

A framework for Dynamic Aperture studies for colliding beams in the High-Luminosity Large Hadron Collider

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Abstract

During the last physics run of the Large Hadron Collider (LHC), Dynamic Aperture (DA) studies have been successfully employed to optimize the accelerator's performance by guiding the selection of the beam and machine parameters. In this paper, we present a framework for single-particle tracking simulations aiming to refine the envisaged operational scenario of the future LHC upgrade, the High-Luminosity LHC (HL-LHC), including strong non-linear fields such as beam-beam interactions. The impact of several parameters and beam processes during the cycle is initially illustrated with frequency maps and then quantified with DA studies.

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Motivation

- □ HL-LHC aims to reach 250 fb⁻¹ per year in the two highluminosity experiments ATLAS & CMS.
- Performance of the accelerator strongly depends on orchestration of several beam and machine parameters.
- A framework for multi-parametric Dynamic Aperture (DA) scans has been developed to guide selection of appropriate parameters in operation. Successfully employed since Run 2 (2015-2018)
- Based on single-particle tracking simulations in the element-by-element HL-LHC lattice, including strong nonlinearities such as **beam-beam effects**.
- Focusing on feasibility of Run 4 (2029) proposed operational scenario during collisions (start & end of luminosity leveling).



Results: Start of luminosity leveling

β^* =1 m, I_{oct} = 410 A, Q[']=15

Tune scans: Based on Run 2 experience, working point that fulfills DA criteria:





Results: End of luminosity leveling

β^* =20 cm, I_{oct} = 100 A, Q[']=15





Correction sextupoles in Q10

- Strong sextupoles in arcs with ATS optics: responsible mainly for correction of chromatic aberrations induced by the triplet.
- □ Installation of additional strong sextupole in HL-LHC lattice is envisaged, namely **MS10 in Q10 of IR1/5**, to compensate for geometric aberrations → beneficial for beam lifetime especially for low $β^*$.
- □ The impact of **not** installing MS10 for **Run 4** is evaluated & discuss potential mitigation strategies.



Results: End of luminosity leveling w/o MS10



DA degradation of 0.5 σ due to the absence of MS10 \rightarrow can be partially restored with other optimizations (IP1-5 phase advance)



Summary

Reviewed **feasibility of the HL-LHC Run 4 envisaged operational scenario** with beam-beam DA simulations during proton-proton collisions.

 Start of luminosity leveling: Head-on beam-beam dominated regime. Reaching DA target is feasible with 1 working point.
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End of luminosity leveling:
 Long-range & octupole dominated regime.
 DA target is comfortably reached with several working points.
• To maintain $DA_{min} \ge 6 \sigma$, working point must be changed during collisions.
 DA reduction (0.5 σ) due to absence of the additional strong sextupole
(MS10) for correction of chromatic aberrations from triplet $ ightarrow$ MS10 is
clearly beneficial. Nevertheless, DA target is reached with "No MS10" in
Run 4 (β^* =20 cm).





Thank you for your attention