UNIVERSITY OF LIVERPOOL

Local Interaction Region Coupling Correction for the LHC and High Luminosity LHC

Author:
Felix SOUBELET

Supervisors:
Dr. Tobias PERSSON
Dr. Rogelio TOMÁS
Prof. Carsten WELSCH

A document submitted in fulfillment of the requirements for the degree of Doctor of Philosophy at the

University of Liverpool School of Physical Sciences

April 28, 2021

For/Dedicated to/To my…

UNIVERSITY OF LIVERPOOL

Abstract

CERN
School of Physical Sciences

Doctor of Philosophy

Local Interaction Region Coupling Correction for the LHC and High Luminosity LHC

by Felix SOUBELET

Lorem ipsum.

Acknowledgements

First and foremost,

"Just don't forget to eat and sleep."

Lee Robert Carver.

Contents

List of Figures

List of Tables

List of Abbreviations

ABP	CERN's **A**ccelerators and **B**eam **P**hysics group
AD	**A**ntiproton **D**ecelerator
ALICE	**A** **L**arge **I**on **C**ollider **E**xperiment
ATLAS	**A** **T**oroidal **L**HC **A**pparatu**S**
AWAKE	**A**dvanced **WAK**efield **E**xperiment
BE	CERN's **BE**ams department
BPM	**B**eam **P**osition **M**onitor
CERN	**E**uropean **O**rganization for **N**uclear **R**esearch
CMS	**C**ompact **M**uon **S**olenoid
DA	**D**ynamic **A**perture
ELENA	**E**xtra **L**ow **EN**ergy **A**ntiproton ring
HERA	**H**adron-**E**lectron **R**ing **A**ccelerator
HiRadMat	**Hi**gh **Rad**iation to **Mat**erials
HL-LHC	**H**igh **L**uminosity **L**arge **H**adron **C**ollider
HSS	CERN's **H**adron **S**ynchrotron **S**ingle particle effects section
IP	**I**nteraction **P**oint
IR	**I**nteraction **R**egion
ISOLDE	**I**sotope **S**eparator **O**n **L**ine **DE**tector
LEIR	**L**ow **E**nergy **I**on **R**ing
LHC	**L**arge **H**adron **C**ollider
LHCb	**L**arge **H**adron **C**ollider **b**eauty
MAD	**M**ethodical **A**ccelerator **D**esign
n-TOF	**N**eutron **T**ime **O**f **F**light
OMC	**O**ptics **M**easurements and **C**orrections
PS	**P**roton **S**ynchrotron
PTC	**P**olymorphic **T**racking **C**ode
RDT	**R**esonance **D**riving **T**erm
SPS	**S**uper **P**roton **S**ynchrotron

Introduction

Some paragraph of text here. Figures to include:

FIGURE 1: The CERN Accelerator Complex as of 2020. This graphic indicates the first year of operation for each accelerator, as well as its circumference. Not to scale.

FIGURE 2: Cross-section of an LHC superconducting dipole magnet (see https://cds.cern.ch/record/40524).

FIGURE 3: The LHC ring with the purpose of the main sections. Not to scale.

As mentioned, each Insertion Region is separated from the previous one by an arc and has its own purpose:

1. IR1 houses the ATLAS experiment
2. IR2 houses the ALICE experiment and the injection of Beam1
3. IR3 houses the off-momentum collimation cleaning (ref https://accelconf.web.cern.ch/ipac2016/doi/JA IPAC2016-WEPMW007.html)
4. IR4 houses the RF cavities to accelerate the beams
5. IR5 houses the CMS experiment
6. IR6 houses the beams extraction to the dumps (ref https://cds.cern.ch/record/1392619)
7. IR7 houses the betatronic collimation cleaning (ref https://cds.cern.ch/record/1056681)
8. IR8 houses the LHCb experiment and the injection of Beam2

FIGURE 4: Integrated luminosity in the four experiments of the LHC during the 2017-2018 LHC Run 2.

FIGURE 5: Beam positions around the two high luminosity Interaction Points during the 2018 LHC Run. The dipoles are represented by blue rectangles while the quadrupoles by red ones.

0.1 The CERN Accelerator Complex and its Upgrade

0.1.1 An Overview of CERN History

0.1.2 The Large Hadron Collider and its Injectors

0.1.3 The Concept of Luminosity

0.1.4 The LHC Performance and the HL-LHC Upgrade

0.2 Optics Measurements and Corrections in the LHC

0.2.1 The need

0.2.2 The practice

0.2.3 ETC

Chapter 1

Theory of Beam Dynamics Pertaining to Transverse Single-Particle Motion in the Large Hadron Collider

Some paragraph before the first section.

1.1 Linear Beam Dynamics

1.2 Non-Linear Magnetic Multipoles

1.3 Formalism of Non-Linear Beam Dynamics

1.4 Phenomenology of Non-Linear Beam Dynamics

1.4.1 Chromaticity

1.4.2 Detuning with Amplitude

1.4.3 Decoherence

1.4.4 Resonances

1.4.5 Dynamic Aperture and the Chaotic Boundary

1.4.6 Linear Betatron Coupling

1.5 Luminosity

1.6 SOMEHOW TALK ABOUT NOTIONS OF MACHINE LEARNING

Chapter 2

The LHC Accelerator

Some paragraph before the first section.

2.1 The LHC Lattice

2.1.1 The LHC Arcs

2.1.2 The LHC Insertion Regions

2.1.3 Error Estimates for the LHC Lattice

2.2 The Operational Cycle of the LHC

2.3 Beam Instrumentation in the LHC

2.3.1 Wirescanners for Transverse Profile Measurement

2.3.2 Beam Position Monitors

2.3.3 BBQ System for Tune and Coupling Measurement

2.3.4 Experimental Kickers

2.3.5 Beam Currrent Monitors

Chapter 3

Modelling and Correction of the Linear Optics

Some paragraph before the first section.

3.1 Measurement and Correction of the Linear Optics

3.1.1 Linear Optics Measurement

3.1.2 Linear Optics Correction

3.2 Comparison of Simulated Linear Optics to Measurement

3.3 Commissioning of Linear LHC Optics for Proton Operation at $\beta^* = 0.3$m, 6.5TeV

3.3.1 Injection (450GeV)

3.3.2 Top Energy (6.5TeV)

3.4 Conclusions

Chapter 4

Interaction Region Local Coupling Correction in the LHC

Some paragraph before the first section.

4.1 Linear Coupling in the Interaction Regions

4.1.1 Overview of the IR Layout Difficulties and Why the Phase Advances SUCK

4.1.2 Twiss with Coupling and Ripken parameters

4.1.3 Equivalency of Ripken and Tracking when looking at beam size

4.1.4 Plan for Correction

4.2 Measuring Linear Coupling in the Interaction Regions

4.2.1 Relating to outside observables

4.3 Proof of principle: Measurement and Correction of Local Coupling in the LHC Interaction Regions

4.3.1 Beam-Based Study of IRs Local Coupling

4.3.2 Simulations of IRs Local Coupling

4.4 Operational Correction Procedure and Run III Commissioning Experience

4.4.1 Procedure

4.4.2 Software

4.5 Conclusions

Chapter 5

Machine Learning for Interaction Region Local Coupling

Some paragraph before the first section.

5.1 The influence of various sources to local coupling

5.2 Identification of Sources with Machine Learning

5.3 Prediction of Corrections for Local Coupling

5.4 Conclusions

Chapter 6

Experimental Measurement and Correction of Interaction Region Local Coupling in the LHC Run III

Some paragraph before the first section.

6.1 Dedicated Measurement and Correction of Local Coupling in IR1 and IR5

6.1.1 Measurement of Local Coupling in IR1 at $\beta^*_{IP1} = 0.3m$

6.1.2 Correction of Local Coupling in IR1 at $\beta^*_{IP1} = 0.3m$

6.1.3 Correction of Local Coupling in IR5 at $\beta^*_{IP5} = 0.3m$

6.2 LHC Run III Commissioning Experience

6.3 Conclusions

Conclusions

Talk about stuff.

Bibliography

Appendix A

Appendix A Title

Some content.

Appendix B

Appendix B Title

Some content.

Appendix C

Appendix C Title

Some content.