The moths of extinction will eat my brain as they will my clothing, and it will all disappear.

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Department of Physics

Lancaster University

A thesis submitted for the degree of

Doctor of Philosophy

August, 2023

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Abstract

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Acknowledgements

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Declaration

I declare that the work presented in this thesis is, to the best of my knowledge and belief, original and my own work. The material has not been submitted, either in whole or in part, for a degree at this, or any other university. This thesis does not exceed the maximum permitted word length of 80,000 words including appendices and footnotes, but excluding the bibliography. A rough estimate of the word count is:

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Only one publication, shown below, has been created directly from the thesis, from which large portions of this published work is used within chapter 3:

moore-rayson-2018-bringing

The following publication have been generated while developing this thesis, and to an extent has guided the thesis into what it has become:

moss-etal-2019-fiesta

moore-rayson-2017-lancaster

el-haj-etal-2016-learning

moore2016domain

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Chapter 1

Introduction

1.1 Introduction

Chapter 2

The ATLAS Experiment and The Large Hadron Collider

2.1 Accelerators and Detectors: Basic Principles

2.2 The Large Hadron Collider

The Large Hadron Collider (LHC) is a modern proton-proton synchrotron located at the CERN complex, outside of Meyrin, Switzerland. At a circumference of approximately 27km the LHC is currently the largest particle accelerator on the planet, and similarly produces the highest centre-of-mass energies for pp collisions, reaching $\sqrt{s} = 13\text{TeV}$. The LHC was constructed from 1998-2008 in the tunnel previously occupied by the Large Electron-Positron Collider (LEP). It extends from from the CERN site, across the French border towards the Jura Mountains and round returning through Geneve and Meyrin. It is positioned on a plane inclined at 1.41% between 45-175 metres underground, a measure to protect both the experimental recordings from a large fraction of cosmic ray interference and the surface from any hazardous emissions from either the particle collisions or the synchrotron radiation.

The LHC is supported by a number of smaller accelerator systems designed

to provide proton bunches of the correct spacing and energy, these are visible in figure 2.1. The acceleration process begins with the injection of Hydrogen anions (H^-) into LINAC[1], which provides an acceleration to energies of 160MeV before the beam is passed on the Proton Synchrotron Booster (PSB)[2]. This continuous beam from LINAC is stripped of electrons and split consecutively amongst the four PSB rings, accelerated to 1.4GeV, and injected into the Proton Synchrotron (PS). PS produces bunches spaced by 25ns, accelerates these to 25GeV, and passes them over to the Super Proton Synchrotron (SPS) for the final energy increase up to 450GeV. Bunches inserted from SPS into the the LHC are brought from 450GeV

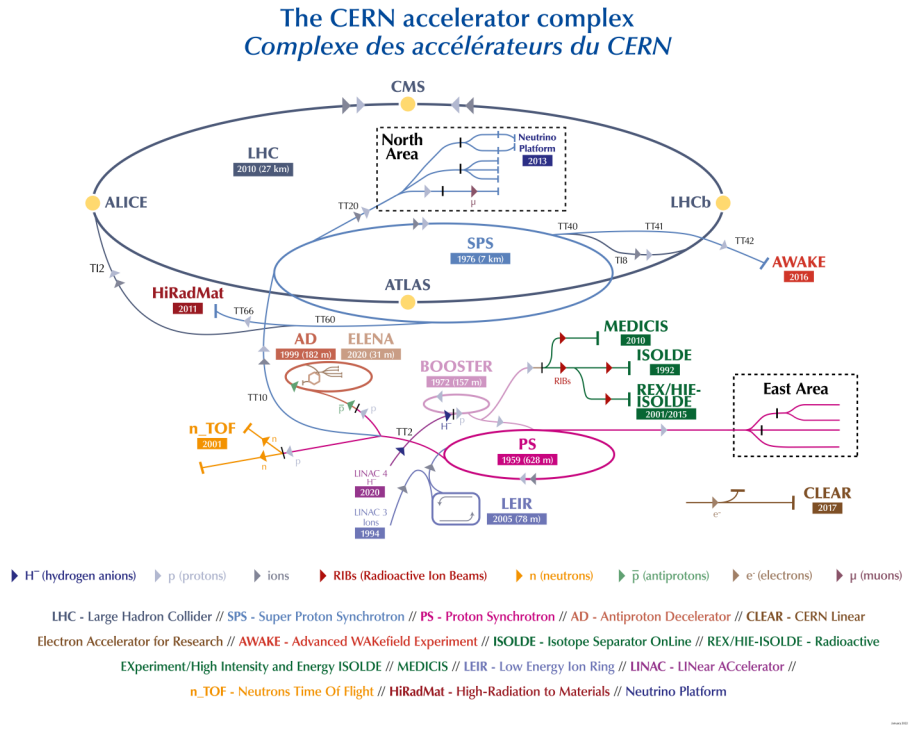

Figure 2.1: CERN Accelerator Complex schematic [1].

up to 6.8TeV over a timespan of approximately 20 minutes. This is driven by the 16 RF cavities around the LHC ring, oscillating at 400MHz each providing up to

[1]This was LINAC 2 until 2020, reaching 50MeV. During Long Shutdown 2 (LS2) this was obsolesced by LINAC 4

[2]idk psb

2MV of acceleration. The LHC beampipe is a dual-core design allowing bunches to travel in different directions allowing the CoM to coincide with the lab frame of a detector. For a single turn through the LHC, a proton bunch will pass through the magnetic field of 1232 superconducting dipole magnets. The magnets are of Niobium-titanite construction, are held at 1.9K, and produce a field of ~ 8.3T. In order to amplify luminosity at the interaction point a focussing effect is produced by the 474 quadropole magnets, arranged into FODO lattices positioned throughtout the circumference.

There are 8 experiments that are part of the LHC, 4 of which are positioned around the circumference. These 4 are ATLAS, LHCb, CMS, and ALICE, located at points 1, 8, 5, and 2, respectively. These experiments are collectively engaged in Run 3 of the LHC. After commissioning and a magnet quench incident in 2008, the LHC entered full operation on 20 November 2009 with first collisions at 7TeV occuring on 30 March 2010. Run 1 concluded in early 2013, delivering a total integrated luminosity of 22.8fb^{-1}. Run 2 began in 2015 and extended into 2018, raising the collision energy to 13TeV, and delivering a total of 140fb^{-1}. After LS2[3] and the upgrades to both the LHC and detectors associated with this, the LHC began Run 3 operations with an increase in the collision energy, again, to 13.6TeV, and is currently ongoing in 2024. After Run 3, the LHC enters Long Shutdown 3 (LS3) for a series of upgrades to prepare for the HL-LHC phase where there is a roughly eight-fold increase in peak luminosity planned, and the total integrated luminosity over the HL-LHC period from Run 4 to the end of Run 6 planned in 2038 will be 4000fb^{-1}.

[3] 2018-2022

2.3 The ATLAS Detector

2.3.1 Overview

The ATLAS Detector[CITATION] as a general-purpose detector with cylindrical geometry and a forwards-backwards symmetry. It has nearly complete coverage, approaching 4π, in solid angle around the interaction point (IP) which is located centrally within the detector layout. The detector is located at Point 1 on the LHC ring, approximately $100m$ below the surface, with the ATLAS control room and supporting infrastructure located directly above at the Meyrin site of CERN.

2.3.2 Coordinate system and common variables

Chapter 3

BLS Trigger; Validation and Purity

Chapter 4

Transverse Momentum Dependent Parton Distribution Functions and Quarkonium Production

Chapter 5

Extraction of TMDs

Chapter 6

Conclusions

6.1 Results

Appendix A

Introduction

A.1 Additional Tables

Some extra tables A.1 that should go in the appendix.

5	6
7	8

Table A.1: Caption

References

[1] Ewa Lopienska. "The CERN accelerator complex, layout in 2022. Complexe des accélérateurs du CERN en janvier 2022". In: (2022). General Photo. URL: https://cds.cern.ch/record/2800984.