TABLE OF CONTENTS

Chapter 1

Experimental Setup

Nice piece of wood in that counter. Nicely planed. Like the way it curves there.

–Leopold Bloom, in James Joyce's *Ulysses*

The work to be described in the present thesis was done at CERN[1], the particle physics laboratory located along the French-Swiss border just outside of Geneva, Switzerland. CERN is comprised of almost 18,000 personnel, of which over 13,000 are researchers in the field of experimental particle physics. It is a truly international workplace, with the personnel comprised of representatives of over 110 nationalities and who are either working directly for CERN[2] or for their respective home institutions — universities or national labs — located across more than 70 countries worldwide [1]. These researchers will generally work at any of the independent experiments located along the various beamlines that network throughout the CERN campus (see Fig. 1.1).

At the time of writing, there are four large experiments[3] taking place currently at CERN, all located along the Large Hadron Collider (LHC): ALICE [2], LHCb [3], CMS [4], and ATLAS [5]. The CMS and ATLAS detectors are general purpose detectors, with broad research programs, whereas the ALICE and LHCb detectors are specialised for the study of

[1] The acronym CERN was historically derived from '*Conseil européen pour la recherche nucléaire*'. Nowadays, 'CERN' has become a standalone name for the lab itself and is currently referred to as the '*Organisation européenne pour la recherche nucléaire*'; or, in English: the '*European Organisation for Nuclear Research.*'

[2] Of the roughly 18,000 researchers in experimental particle physics, only about 5% are employed directly by CERN itself.

[3] For the most part, one can interchange the words 'detector' and 'experiment' when referencing large-scale, long-term particle physics experiments such as those that have taken place over the past few decades: the detectors tend to take on the role of representing the entire collaboration of physicists, engineers and associated personnel, as well as the entire scope of the associated research programs.

heavy-ion collisions and b-hadron physics, respectively.

This chapter will present a brief introduction to the workings of the LHC in Section 1.1. In Section 1.2, given that the present author is a member of the ATLAS collaboration, a detailed description of the various components that make up the ATLAS detector will be presented in Section 1.2.

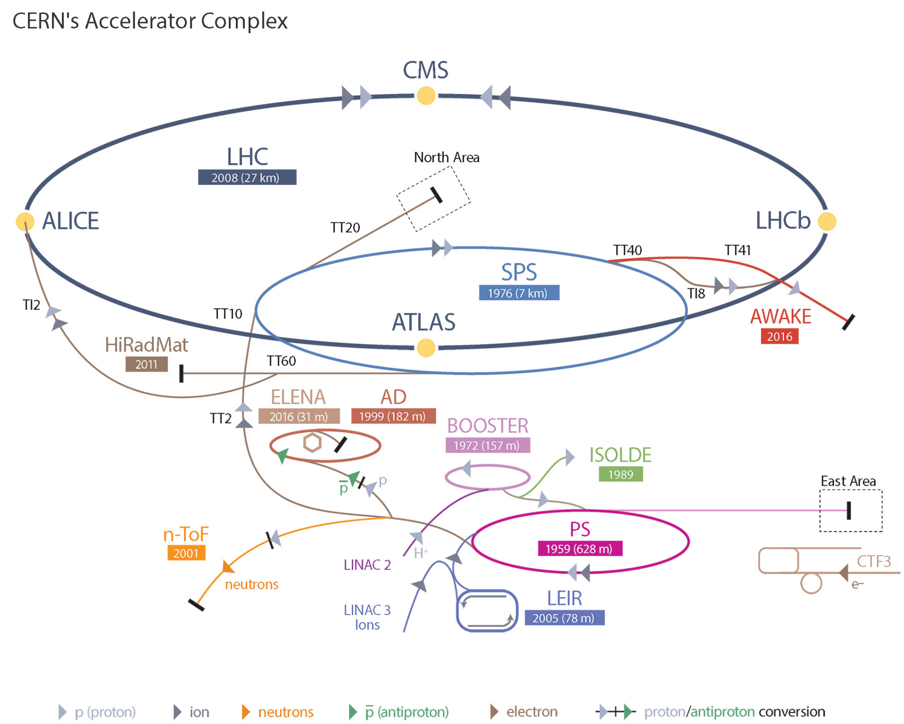

Figure 1.1: Illustration of the various beamlines, accelerator and storage rings, and experimental points that the CERN accelerator complex is home to. The protons that circulate through the LHC, and that are eventually made to collide inside the ATLAS detector, follow the path: Linac 2 $\rightarrow$ Booster $\rightarrow$ Proton Synchotron (PS) $\rightarrow$ Super Proton Synchotron (SPS) $\rightarrow$ LHC.

1.1 The Large Hadron Collider

The LHC [6] is a circular particle accelerator, with a 27 kilometer circumference, located at an average distance of 100 meters beneath the surface of the Earth. It is nominally used for proton-proton (pp) collisions, wherein two counter-rotating beams of protons are made to collide head-on at specific interaction points (IP) along the 27 kilometer ring, but can also be run in heavy-ion configurations wherein proton-lead (p-Pb) or lead-lead (Pb-Pb) collisions take place.[4] The pp collisions take priority over those of the heavy-ions, with the collisions each year consisting of only a few weeks in the winter for the heavy-ion configurations and typically six to seven months for the pp configuration. The LHC is designed to accelerate protons to a center-of-mass energy of $\sqrt{s} = 14\,\text{TeV}$.

The LHC was planned as the successor to the Large Electron Positron (LEP) collider, which was in operation between the years of 1989 to 2000. LEP is still the most powerful lepton collider to date, having maximal electron-positron center-of-mass collision energies of 209 GeV. After LEP, the particle physics community knew that the next collider needed to have multi-TeV collision energies; either to be able to probe from all angles any new physics discovered at LEP, or to provide the necessary power to probe still-elusive hints of BSM physics. At the very least, given a non-discovery of the Higgs boson at LEP, the community would need a discovery machine powerful enough to produce electroweak-scale Higgs bosons and a multi-TeV collider — as we now know — is sufficient for this job.

To avoid the exorbitant costs in civil engineering and real-estate works associated with constructing an even larger tunnel, it was decided that the LHC should be housed in the already-existing tunnel that housed the Large Electron Positron (LEP) collider, in operation from 1989 to 2000. LEP, a *particle-antiparticle* collider, was able to take advantage of the fact that particle and anti-particle beams can be made to occupy the same phase space within a single ring: the same magnetic fields could produce counter-rotating electron (negatively charged) and positron (positvely charged) beams.

1.1.1 Injection Chain

1.1.2 The Concept of Luminosity

The Large Hadron Collider (LHC) can be thought of as the final part of the particle-beam injection line that is comprised of many parts whose goal is to accelerate protons, or other particles, to the energies requisite for CERN's large experiments to do perform fundamental physics research at the high-energy frontier.

1.2 The ATLAS Detector

[4] More rarely, the LHC can also be used to circulate gold (Au) ions. There are even plans to have proton-oxygen (p-O) runs in the future, which will allow for the LHC experiments to provide research that potentially complements dark matter research that relies on cosmic-ray air showers.

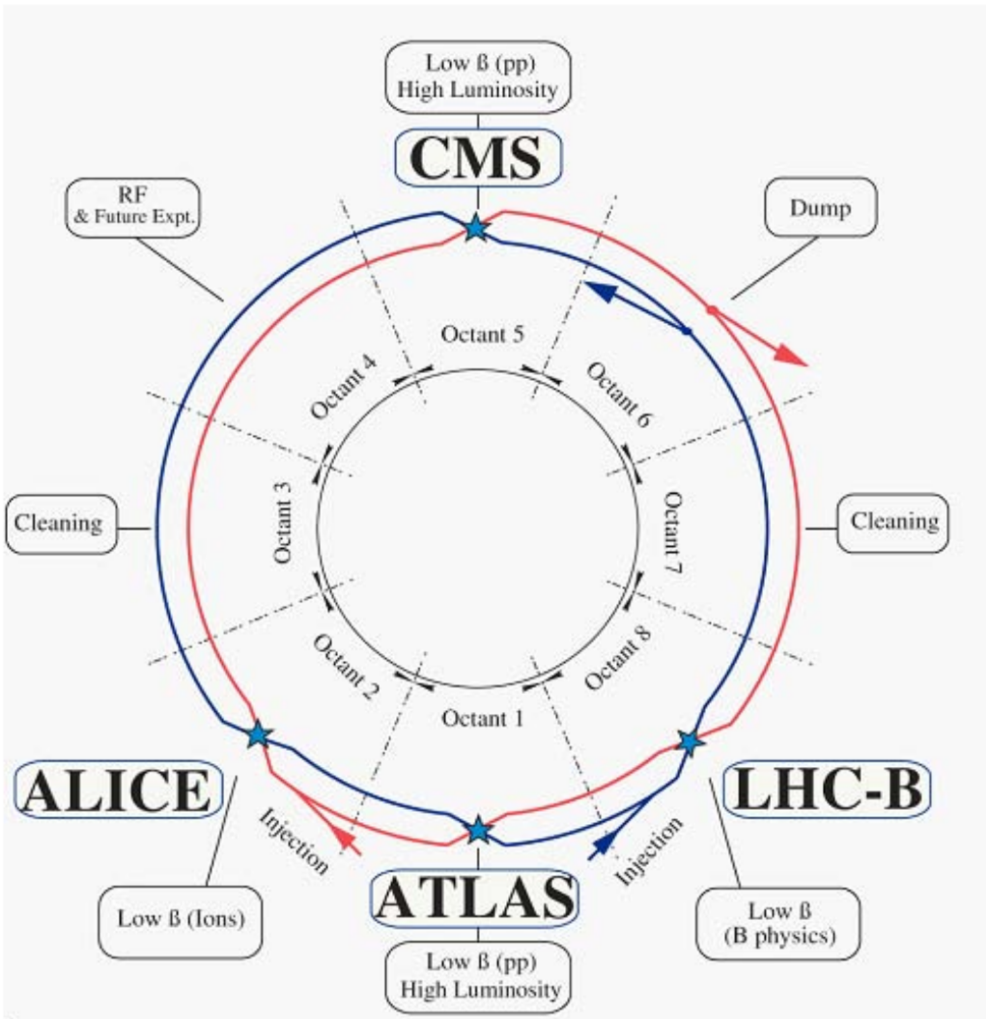

Figure 1.2: Layout of the LHC and its two counter-rotating beams. Beam 1 is in blue and rotates counter-clockwise. Beam 2 is in red and rotates clock-wise. At the center of each octant is a straight section which houses the experimental caverns or LHC beam facilities. At the boundaries of each octant are located the curved sections. Figure taken from Figure 2.1 of Ref. [**Evans˙2008**].

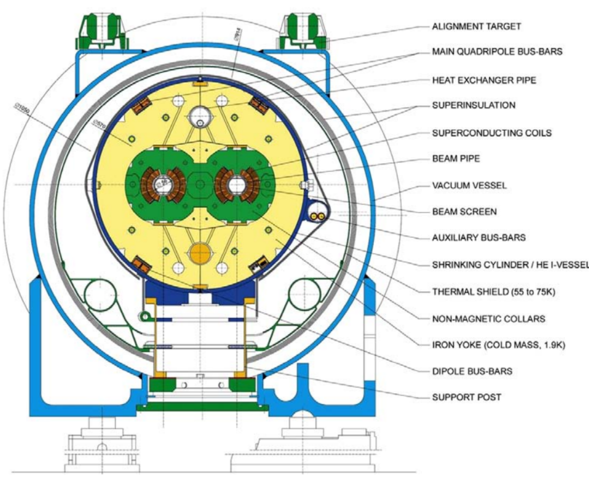
ALIGNMENT TARGET
MAIN QUADRIPOLE BUS-BARS
HEAT EXCHANGER PIPE
SUPERINSULATION
SUPERCONDUCTING COILS
BEAM PIPE
VACUUM VESSEL
BEAM SCREEN
AUXILIARY BUS-BARS
SHRINKING CYLINDER / HE I-VESSEL
THERMAL SHIELD (55 to 75K)
NON-MAGNETIC COLLARS
IRON YOKE (COLD MASS, 1.9K)
DIPOLE BUS-BARS
SUPPORT POST

Figure 1.3

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