Chapter 1

Introduction

High energy particle physics seeks to explain the existence of a set of fundamental particles whose interactions determined the evolution of the universe. The set and their interactions are described shockingly well by the Standard Model (SM) of particle physics; however, the questions the SM does not address motivate more experimentation.

Accelerators collide particles to generate interactions that can be captured by detectors and subsequently studied. The Large Hadron Collider (LHC) [2] at CERN will remain the world's most energetic particle accelerator for at least the next decade [1], making it an indispensable tool for studying interactions in an environment as close as can be simulated to the early universe. The ATLAS experiment [4] is one of the LHC's general-purpose particle detector arrays, used to detect the products of LHC collisions. A feat of engineering, every detail matters. This work showcases one example of how precise positioning of electrodes in particle detectors is necessary to study the interactions of particles in high-energy collisions.

The High-Lumnosity Large Hadron Collider (HL-LHC) project [1] was approved to combat the plateau in statistial gain of recording particle collisions at the LHC. Being the most energetic particle accelerator, the LHC still offers unique physics opportunities for studying the Higgs and electroweak sectors of the SM [3]; if study at the energy frontier is to continue, the LHC must go on. The HL-LHC upgrade aims to increase the luminosity of the LHC by up to a factor of 7 in the next 10 years, which ultimately increases the number of meaningful collisions. Naturally, various sub-systems of the experiments used to capture the outcomes of the collisions will require upgrades to handle higher collision rates and background radiation rates than they were designed for.

During the 2019-2022 Long Shutdown of the LHC, the most complex upgrade of the ATLAS experiment is the replacement of the small wheels of the muon spectrometer with the so-called New Small Wheels (NSWs) [5]. The NSW upgrade addresses both the expected decrease in hit efficiency of the precision tracking detectors and the high fake trigger rate of the muon spectrometer. Two different detector technologies will be installed, stacked on the NSW frame: micromegas (MMs) and small-strip thin gap chambers (sTGCs). MMs are optimized for precision tracking while sTGCs are optimized for rapid triggering, although each will provide complete coverage and redundancy over the area of the NSW. Canada was responsible for providing 1/4 of the required sTGCs.

To reduce the fake trigger rate, the NSW will provide better track angular resolution to the ATLAS trigger system to reject tracks that do not originate from the collision [5]. sTGCs provide 100 µm position resolution per detector plane [6], and are stacked in four (called an sTGC quadruplet) to provide 1 mrad angular resolution on tracks [5, 7]. sTGCs are gas ionization chambers where a thin volume of gas is held between two cathode boards. One boards is segmented into strip electrodes of 3.2 mm pitch. The position of the particle track in the precision coordinate can be reconstructed from the strip signals [5] to within the required position resolution [6].

Precise position resolution is naught without accurate positioning of readout electrodes in ATLAS. The ATLAS alignment system is able to position the surface of three sTGC or MM quadruplets traversable by a muon track with respect to one another within 40 µm. The internal geometry of the detectors must be controlled or corrected for to within the chambers' position resolution [5]. Corrections to the position of strip electrodes in sTGC quadruplets are in their final stages. The corrections are done with characterization data collected throughout the construction process. At the cathode board level, strip electrode positions are digitized with a coordinate measuring machine (CMM) [8]*I'm citing Carlson but should I be citing a paper that deals with the global context? E.g. something at the collaboration level*. At the quadruplet level, sTGC quadruplets are characterized with cosmic rays over the whole area and with an x-ray gun at positions that will be tracked by the alignment system. Cosmic muon data (cosmics data) can be used to measure relative strip position offsets in a local area with respect to the strip patterns on other layers, which characterizes the strips' alignment but does not allow the strips to be positioned in the absolute ATLAS alignment system. The x-ray method [9] is able to measure offsets of the strip pattern near the x-ray gun in a coordinate system accessible to the alignment system; however, it is limited to a handful of positions on the surface of the quadruplet and should be validated by an independent method. In this work, cosmics data is used to measure relative strip offsets, the x-ray method is validated with cosmics data, and how this work fits into the overall alignment scheme is presented.

Chapters **??** and **??** give more background on particle physics, the LHC, ATLAS, the NSWs, and sTGCs. In chapter **??**, the cosmic ray testing procedure and how the position of the strips can be probed with cosmics data is presented. Chapter **??** introduces the x-ray method, and in chapter **??**, the x-ray offsets are validated with cosmic muon data. The thesis concludes with a summary and outlook in chapter **??**.

APPENDICES