Analysis of Test Data for the LHC-CMS Endcaps

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Abstract

I provide a brief examination of the physics behind the Compact Muon Solenoid (CMS) detector for the Large Hadron Collider (LHC.) The reasons why it is being built and its capabilities will be examined and delineated. Finally I will describe the work that I did to analyze test data for the Endcaps of the CMS and examine the accuracy of the Cathode Strip Chambers (CSC) that will be used in it.

The LHC-CMS Project

The Large Hadron Collider (henceforth LHC) is a large hadron-hadron collider that is being constructed at the European Organization for Nuclear Research (CERN) in Geneva. It will be capable of accelerating two beams of protons to 7 TeV each, creating a total collision energy of 14 TeV, by far the largest energies ever examined in the field of particle physics. The CMS detector for the LHC is a multi-purpose detector that will be used to help explain the Standard Model of Particle Physics and Higgs Theory.

Higgs Theory is a formulation that is predicted by the Standard Model to explain the very basic concept of inertia or mass itself. According to Higgs Theory; the breakdown of gauge symmetry predicts the existence of a particle called the Higgs boson which mediates the interaction of all elementary particles. This is similar to the W and Z
bosons which mediate the electro-weak interaction. It is a missing link in the Standard Model, that when found will be of fundamental importance.

Finding the Higgs boson is one of the main reasons why the LHC is being built. The Higgs boson is predicted by theory to have a mass somewhere between 80 GeV and 700 GeV, thus the need for an accelerator with such high energies as the LHC. Since the Higgs boson is so short lived, its existence can only be detected through its decay products. The most direct and characteristic way of detecting the Higgs is through a decay path to 2 Z bosons and from those to 4 muons.

\[
p p \rightarrow H^0 \rightarrow Z Z \\
\rightarrow \mu^+ \mu^- \\
\rightarrow \mu^+ \mu^-
\]

This is the decay path for the most likely mass of the Higgs boson which is between 130 and 700 GeV. However, for Higgs boson masses less than 130 or greater than 500 GeV; the decay paths could be to 2 photons or to 2 leptons and 2 jets respectively. Thus the need for a versatile detector that can detect any and all of these decay products. This detector is the Compact Muon Solenoid.

The CMS is composed of four main systems. The innermost structure is the Silicon Tracker that will be used to detect decay products with lower transverse
momentum that will be trapped by the 4 Tesla magnetic field generated by the detectors’ Superconducting Solenoid. The next layer is Electromagnetic Calorimeter. This structure will be used to detect photons and electrons that are possible decay products. Outside of the Electromagnetic Calorimeter is the Hadron Calorimeter that will be used to detect Hadrons and jets. The outermost layer is a sandwich of iron return yokes and Muon Chambers that is designed to isolate muons and measure their momenta.

The Muon Detectors are composed of Cathode Strip Chambers, Resistive Plate Chambers, and Drift Tubes. Only the two former are in the endcap region of the detector. The CMS group at OSU has chosen to work on the Cathode Strip Chambers in the endcap of the detector. The group is responsible for the construction of about 540 CSC’s and the accompanying electronics.
Analyzing the Test Data

My task this summer was to help analyze test data for a CSC to determine what level of accuracy could be obtained in measurements of the paths of muons. This data was produced by allowing a sample CSC to be hit by cosmic muons.

A CSC works by having several layers (in this case 6) of cathode strips separated by anode wires. As a muon passes through the chamber, it ionizes the gas in the chamber. The free electrons are collected by the strips and the voltage generated is read off and used to calculate the position where the muon passed through each layer of the chamber. These positions are then fitted to a linear path using a least squares fit.

The following figure is a graphical representation of this methodology. Each of the planes in the CSC is represented by the horizontal lines. The positions where the muon passed through each plane are represented by the dots and the line is the trajectory of this muon event.
We wrote a program in C to analyze the test data. The first attempt at this was a very simple weighted average over the strip with the highest recorded voltage and the two adjacent ones to find where the muon passed through each layer or plane of the chamber. This produced six points, one in each plane, that were then fitted to a line to find the trajectory of the muon. The following figure is a histogram of the differences between each of the points found through the weighted average and the point of intersection of the fitted trajectory with the corresponding plane, i.e. a measurement of the error in the fit.
As can be seen from the figure, the RMS error is 0.5215 cm. This is much higher than the 400 micron error that was achieved earlier in a similar test of this system. Due to this order of magnitude lack of accuracy we were forced to reexamine both the methodology of the fitting program and the actual structure of the detector itself.

Since the CRC’s are shaped somewhat like trapezoids, but the number of strips along the height of the trapezoid remains the same, thus the strips widen from being .9cm to 1.6 cm in width. In order to improve the accuracy of the detectors, the strips staggered between layers, so that the strips of two adjacent layers do not lie on top of one another. After compensating for both of these aspects of the design of the system, we searched for any sort of systematic error. We found that the strips are not perfectly parallel as they should be, but are in fact slightly skewed.

Examining the methodology of the fitting program itself we found that simply taking a weighted average of the voltages of the strips was causing our muon-plane intersection points to drift towards the edges of the strips. We were thus forced to find a more rigorous method of describing the effect that we were measuring. This effect is known as an electron cascade or avalanche, where the electrons knocked off of the gas molecules are accelerated to high speeds and thus ionize other gas molecules in a chain reaction. The distribution of these electrons being attracted to a cathode is known as a Gatti curve.

Examining the following figure it is clear that after applying all of these effects, the data analysis showed an RMS error of 545 microns, which is comparable to the best values that have been obtained in earlier tests.
References


3. Electron Cascade Effect:
   http://www.fortunecity.com/greenfield/bp/16/electroncasc.htm

4. Discussions with Stan Durkin

5. Discussions with Jason Gilmore