Evidence of the Higgs Boson

Bethany Ann Ludwig; Chris Gopez; Shunhua Lin; Al Pham; Manuel Gonzalez; Andrew Daniel Rocha; Jose Chavira; Edgar Perez
University of California Riverside, Mount San Jacinto College, Riverside City College, San Bernardino Valley College & Pasadena City College

Background
The Higgs boson was first theorized in 1964 as a component particle of the Higgs Field which permeates the entire universe. At particles which make up the world we know gain mass with their interaction with the Higgs Field through a process known as the Higgs Mechanism. Without this interaction, all particles would just float about space freely at the speed of light. As this is not the case, the Higgs Field is essential to the standard model of physics.

Abstract
In order to prove the existence of the Higgs Field, we test for the existence of the Higgs boson. This particle exists for an extremely short period of time, about 1.6 x 10^-25 seconds, before it decays into quark, lepton, or boson pairs. More specifically, a Higgs will decay into a particle and its corresponding anti-particle. Because the Higgs is so fleeting, it cannot be measured directly. Instead, one can be rarely created as a byproduct of particle collision at near the speed of light before it decays again to other massive particles. This is accomplished in the Large Hadron Collider where detectors measure all the byproducts of collisions and recreate the decay process. If the process matches a known decay pathway for the Higgs, it may be reasonably concluded that a Higgs boson was present.

Methodology
2 of our members started by looking at physics objects for two photons (ϒϒ) to be present, then we would select those and then moved on to the next event. If not, then we would check for 4 muons (μ+μ-μ+μ-) then select those, if four were not found then looked for 2 muon (μ+μ-) and 2 electron (e+e-) ensuring they are in pairs and selected in the correct order. If no muons were available then we looked for 4 obvious electrons (e+e+e+e-). If still no candidates were found then reselected physics objects then moved on to the next event. 4 of our members decided to look for the 4 muons (μ+μ-μ+μ-) first then the 2 muon(μ+μ-) with 2 electrons, if still none then search physics objects for photons if 2 were not found then searched for 4 electrons and if none were found then moved on to the next event. 2 members methodology did not follow the guidelines and their data was omitted. Our foundation of understanding the ATLAS Detector on the Large Hadron Collider and how each layer caught different particles was essential. The first layer caught protons and electrons while the outer layers caught the muons. Our observations for the photons were probably the most difficult since they did not leave a track like the electron clouds or the long muon tracks.

Data Analysis
After reviewing the data from all the team members and seeing that there was a misunderstanding with 2 of the team members' interpretation of the data. We reevaluated the entire data table to obtain accurate results. Analyzing the dilepton invariant mass we found substantial peaks at approximately 3 GeV, 10 GeV, 91 GeV, and 1000 GeV, these are mass coincident with the mass of a muon, a charged lepton, a photon, a neutral boson, and “fake” Z respectively. Viewing the graph of the 4 lepton events we see a substantial amount of background involving the 2 e-μ+ pairs reducing the ability to determine a given area of significance. However, after looking at the events of 4 muons and e-μ+μ-μ+, we see less background and an abundance of events at approximately 125 GeV. The last set of data we reviewed was of the diphoton events. We concluded from seeing a noticeable rise from the downward trend of the histogram between 120-130 GeV giving a good indication of where the mass for the object we were looking for.

The calculation of the energy of the Higgs boson is:

\[ E^2 = p^2 + m^2 \]

and solving for the invariant mass we derive:

\[ m = \sqrt{E^2 - p^2} \]

From the law of conservation of energy and momentum we have:

\[ E^2 = p^2 + m^2 \]

Substitution of these terms yields this equation:

\[ (E+p)^2 = (E-p)^2 + 4m^2 \]

Zooming it at the 4 Muons peaks, at approximately 125 GeV (at the 2 electrons and 100-125 GeV (Higgs boson)

Summary
For our research, we focused on four specific pathways:

H → γγ
Z → μ+μ-μ+μ-
ZZ → μ+μ-μ+μ-
ZZ → e+e-e+e-

Thousands of collision events as modeled by the CMS detector in the Large Hadron Collider we searched for signs of these particles. The CMS detector consists of a tracker, an electromagnetic calorimeter (E-Cal), hadronic calorimeter (H-Cal), and a muon identification detector (Muon-Det). Each particle detected has a unique signature in the event data. Photons (γ) leave a localized energy deposit in the E-Cal but the inner detector can track its progress, leaving a “track” to the energy deposit. Muons (μ) interact very little with the detectors but can be tracked. Their signature is a track crossing through all the detectors.

All the particles counted were used to create a histogram for signing the mass of the particles detected to their frequency. Upon further independent research, we were quite satisfied of this result since we obtained most of our events in the theoretical value which is calculated to approximately 125 GeV.

References

Acknowledgements
Prof J.W. Gary, Mr. C. Richards, Ms. M. Nunez, Ms. N. Tran, Prof. O. Long,
U.S. Department of Education and UCR Department Physics and Astronomy