Search for Higgs boson via Z boson and γ decay mode of Higgs boson in p p collisions at 13 TeV at ATLAS

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Declaration by the research Scholar

I hereby declare that the entire work embodied in the report is the result of investigations carried out in the paper "A search for Zγ decay mode of the higgs boson in pp collisions at $\sqrt{13}$ TeV with the ATLAS detector" available at `https://arxiv.org/abs/2005.05382`. All the results that are present in this report are not produced by me rather by the rightful authors of the paper mentioned above. My sole objective was to understand the paper and present in the seminar in the **School of Physical Sciences**, Indian Institute of Technology Mandi, India. However, the report is written by me in my language. Proper reference of all the results and graphs are provided and still if some results went un-referenced then I am sorry in anticipation. The report will be modified at first notice. I can be reached using the email **theswaruptushar@gmail.com** . All the contribution goes to the rightful owners who conducted the research.

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Contents

1 Abstract

This report contains the study of higgs decaying into a Z boson and photon. Efforts have been put to study the method of finding the evidence for the existence of the higgs boson available in the paper 1. This report contains the study done at ATLAS detector of LHC (Large Hadron Collider). Collisions of proton ions with proton ions were done with center of mass energy 13 TeV. The integrated luminosity in this study was 139 fb^{-1}.

2 Introduction

High energy is the branch of physics in which mainly the study about the origin of the universe is done. That is, how everything started. What was initially and how things developed to current scenario like planets, stars ,black holes and all the rest of the things. There are a no of theories about the origin of the universe.Out of these the most prominent that is believed by the most of the people is the theory of the Big bang. This theory states that initially there was nothing except a singularity. From this singularity everything started. The universe started expanding and took the form of what is there today. Though still there are people who don't believe this theory is true, but so far it is the most recommended theory.

According to this theory the singularity bursted and it started to expand. Due to the expansion a lot of processes happened contributing to what we have now. After big bang there was a large amount of energy focused within small volume. Then the universe started to expand further. It can be said that this expansion of universe was like cooling. Then as universe keeps on expanding particles got produced which were initially in the free state known as quark gluon plasma. Particles at this instant were not even interacting with each other. Then later as the universe expanded further, the particles started interacting with each other. They started forming bound states,like hadrons, mesons. As time further progressed these bound states became even heavier by combining even further with other particles. Then later on atoms were formed which even keeps on interacting with other atoms then formed molecules. Thus as the time keeps on due to the interaction between matter new objects kept on forming. Galaxies formed, large masses of gases formed, stars formed, planets formed and today a lot bodies are there.

At CERN, this process is recreated ,that is particles or heavy ions are collided at relativistic energy and compressed to large energies in small volume. From this point the system starts expanding or cooling and then the ongoing processes are observed as the system expands. After this, statements about the different interactions, matter or radiation in our universe have gone through, are made. Statements about different phases the universe may have gone through are made, different processes of nature are explained and the mechanism of interactions are used to make life easier. But the point from which the system created in the detectors starts expanding and continue the process the of big bang depends on the energy with which the particles or heavy ions are collided. So it is tried to make the accelerators which can accelerate particles to high energies, so high that early stages of universe evolution can be achieved and studied in the labs.

In Particle physics, particles available in nature are discovered and their properties are studied and how interactions takes place, which explains several phenomena of nature, are explained 2. AT CERN experiments are carried out since a long time now and a number of elementary particles have been identified. Along with this a number of properties have been studied of the particles. Also a number of phenomena have been explained using these particles. To correlate all the different kinds of particles available in the nature, a standard model has been proposed which categories particles into groups based on their properties.

Standard model basically explains the fundamental forces strong nuclear force ,weak nuclear force and electromagnetic force (as gravitational force is very weak it is not considered in this model) found in the nature. This model contains elementary particles known to us up until now3. It contains the elementary particles which are found in nature. Elementary particles are particles which are not made up of any other particle. With the help of these elementary particles standard model explains the working mechanism of the fundamental forces. In the standard model the particles are grouped as leptons, quarks and Interaction force carriers(Bosons). Quarks are the particles from which hadrons are made up of. They contains fractional electric charge 4. They also have color charge.There are six quarks having name up, down, charm, strange, top, bottom. Besides they have baryon number and half spin. Leptons are the particles which do not have color charge,have half spin,have integral electrical charge.

In leptons comes electron, muon, taun ,electron-neutrino, muon-neutrino, taun-neutrino. Now remains the force carriers/intermediaters. They are also known as exchange particles. These are the particles which are responsible for various interactions in the nature. The particles are also grouped in different generations. First generation contains up, down quark and electron and it's neutrino, second generation has charm, strange quark and muon and it's neutrino. Third generation contains top, bottom quark and taun and it's neutrino. Besides there are force carriers photon ,Z^0, W^-, W^+ bosons and glouns.The Z^0, W^-, W^+ bosons are also known as intermediators as they mediate weak nuclear force.

A new boson has been added in the standard model since 2012 5. It is the higgs boson. This particle is responsible for all particle's mass. Higgs has a mass 125.09 GeV with an uncertainty of $\pm$0.21 GeV. It is a scalar boson. It has both electric and color charge zero. Spin of higgs is also zero. Parity of this particle is +1. It has hyper-charge of +1 and iso-spin -1/2. This report contains study of the search for higgs via decay mode of higgs to photon and Z boson which further decays into pair of leptons. The possibility of Higgs decaying through this channel is (branching fraction) is 1.54$\pm$0.09. The mass of Higgs is determined by retracing the decay process. That is by combining the four vectors of after-products of the decay process. The mass of higgs is found 125.09 GeV with a statistical uncertainty of $\pm$ 0.21 GeV and systematic uncertainty of $\pm$ 0.11 GeV.

Systematic uncertainty are the uncertainty which arises due to instrumental effect. This is the error which is obtained every time the measurement is done. This is basically the offset error of the detector. It can be calibrated easily. Before doing actual collisions data is taken with some radio-active material placed at the centre of the detector. As the particles which will be emitted by the radio-active substance is known beforehand, this data is used as offset to remove detector effects during recording data from the collisions. The statistical uncertainty is the error which is random and is obtained from various effects. One of it's source is like every time measuring the mass of electrons in the detector one will not get the same value every-time. Sometimes the detector will measure 0.511 MeV, sometimes 0.514 MeV and likewise. Therefore always there is a uncertainty in the measurement of mass of electron. The average of all the statistics of electron's mass is taken and then compared to the true value.

As compared to the results of previous runs data at LHC this time there are important update in the analysis. The amount of data this time was greater than previous runs for analysis. Events were selected more precisely. There are a number of decay channels for the process of interest of this report. Like the Z boson can decay to pair of electron and positron or to pair of muon and anti-muon. Also there is non-removable error from the non resonant production of photon and Z boson. There is also error from missing transverse energy which is discussed later in this report. However, there is no way to take into account the effect of error from this source. So the events containing the missing transverse energy is not included in the analysis. The analysis is done for all possible channel and data is fitted to observe the property of higgs.

Up until now we know particle's that are there in the standard model, but is that all! Obviously not, there may be other exotic particle which are still unknown and which can explain several new phenomenon's of nature or known unexplained phenomenon's. At CERN when ions (heavy/light) are collided at high energies then while measuring the processes like decay of a heavy particle to some other particle then measurements of momentum and energy of particle are taken, it is found that the energy is not conserved. That is some energy is missing 6. That missing energy can arise due to several reasons like energy carried by some neutral particle that went undetected through the detector, the precision with which detector can measure the energies of emerging particles, energy taken away by some unknown particle which may explain physics beyond standard model like explaining the dark energy or energy carried by particle which came out at large pseudorapidity and several other possibilities are also there.

So if the missing transverse energy can be measured more accurately several possibilities of missing transverse energy can be eliminated like if the neutral particles are measured in much better way the possibility of particles like neutrino's taking away energy can be removed or the detectors can be improved so that they can measure physical observable more accurately like momentum. Then the possibility of uncertainty in measurement can be made very less.

By eliminating the possibilities of current physics and after doing so if there is still some missing energy it can be said that the energy is carried away by some other new particle or group of particles which are unknown to us and could even find some undiscovered particles which can explain several things in nature. So methods which can bring improvements in the measurement of energy are constantly being developed so that other exotic particles can be discovered that still exist in theories or not even in them. People working at CERN measure transverse (Direction perpendicular to the beams direction) components of physics observable at the detectors like transverse momentum or transverse energy. It is because of the geometry of the detector that we can measure transverse quantities better than at any other direction's.

As in general the detector is like a big barrel. Nearly, In the center of it the collisions happened then particles come out, based on the energy of the colliding beams, mostly in the transverse direction i.e. vertically like in this case where beams are collided with energy 13 TeV. Missing Transverse energy is the transverse component of the missing energy. The terms missing transverse momentum and missing transverse energy will be used interchangeably from now on as they have the same meaning. More formally it is the energy imbalance in the transverse plane of colliding beams abbreviated as the MET. MET is used instead of MTE because of the convention scientists at CERN are using.

The notation "MET" is in use since long time so it's not a wise act to change this notation. So MET is basically short notation for missing transverse energy. Majorly, missing transverse energy is due to particles like neutrinos or potential weakly interacting non-standard model particles or particles which after interaction/no-interaction emerge out at large pseudorapidity.

Missing energy can be found in a number of processes like decay of higgs. If the decay of higgs like in a pair of muons (Here pair of muons means one muon and one anti-muon) is observed then sometimes the pair of muons came out opposite to each other implying that higgs decay only into muons pair (As to conserve momentum they came out opposite to each other). But in some cases the muons pairs came out at some angle which means that the a third particle must came out along with the muons pair which can take the left energy and will have momentum such as required for momentum conservation.

Up until now people, for analysis, only consider those events in which pair of muons emerged opposite to each other so that the effect of missing transverse energy can be mitigated and the properties of higgs can be studied with much more accuracy. However, the signal strength of such events is very less so the confidence level with which the properties are determined also decreases. If the effect of missing energy can be understood then the discarded events can also be included in the analysis and the signal strength of corresponding parent particle will increase (Higgs in this study).

3 ATLAS detector

At LHC (Large Hadron Collider), at CERN, there are four detectors ATLAS, ALICE, CMS and LHCb. This works is biased towards ATLAS detector i.e. this work is in accord with ATLAS detector. ATLAS detector is located in Switzerland. Studies about new physics is

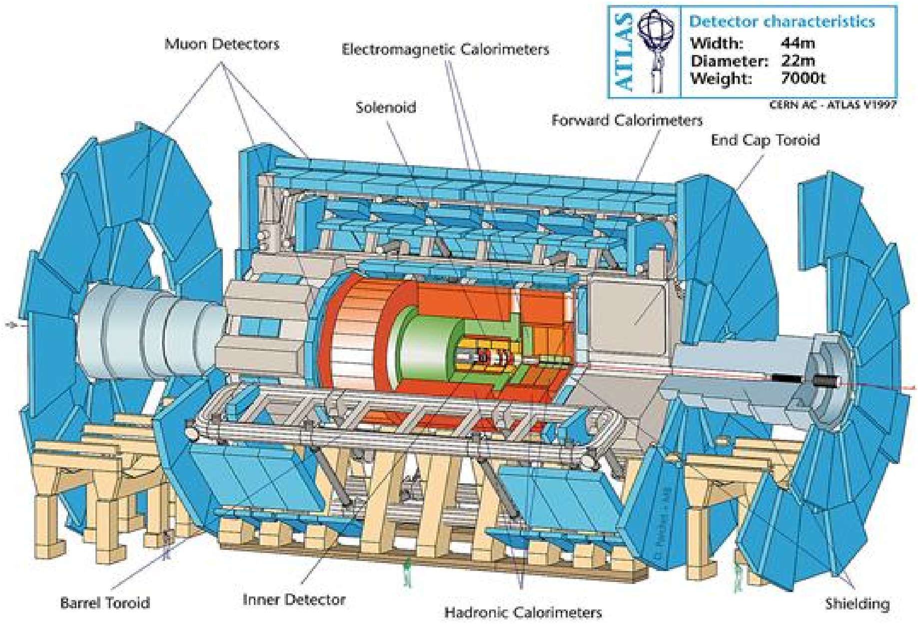


Figure 1: A transparent view of the ATLAS detector displaying all it's parts. 15

mainly carried out in this detector and CMS detector. The ATLAS detector has eight coils which produces a magnetic field of 3.5T. It is used to measure hadrons,leptons, photons, muons etc. It consists of various sub-detectors which works on different principles and detect particles produced after the collision. At ATLAS the coordinate system used is as, the direction of beam is taken as the z axis and the direction perpendicular to it pointing at the center of the LHC ring is taken as x axis. The direction perpendicular to both of these directions is taken as y axis. The Axis/Coordinate system used in the ATLAS detector can be understood more deeply by referring the figure 2.

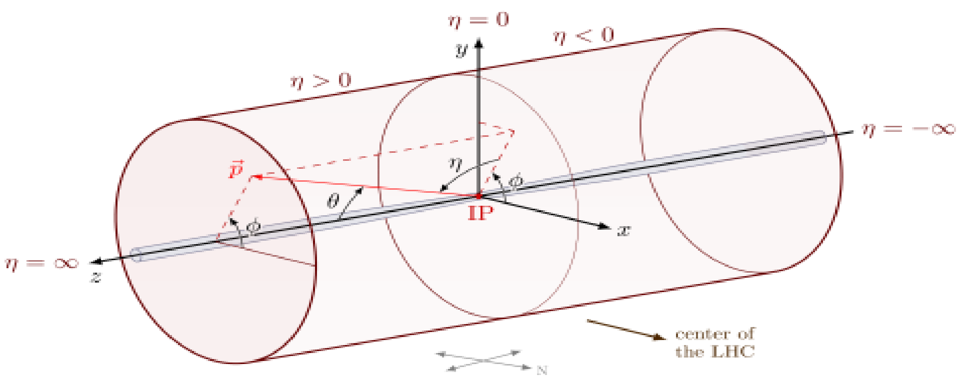


Figure 2: Coordinate system used in ATLAS detector. 16

3.1 Inner tracking system

The inner tracking system also known as (ITS) is first part the particles interacts with in the detector. It is the nearest sub-detector to beam pipe. It is made up of three parts, pixels, transition radiation tracker (TRT) and semiconductor trackers also known as SCT. The pixels are made up of layers of silicon and are present in the form of very small molecules that is have high granularity. Because of this the pixels are able to measure the origin of every charged particles produced in the collision. It can be used only for charged particles. Neutral particles go undetected as they don't interact with silicon atoms. After pixels comes SCT. The SCT are also made up of silicon. The difference between pixels and SCT is that, in SCT silicon is arranged in a barrel like structure.

There are 4 layers of such barrels. After it comes the TRT. It is made in somewhat straw pipe like structure. The pipe are known as drift tubes. There is gaseous mixture filled in these pipes. The gases filled mostly consists of argon and xenon. The pipe is made negatively charged by applying negative voltage on it's surface. There is wire in the middle of these tubes which is of tungsten. This wire is connected to ground. The particles passing through these tubes ionise the gas and the electrons produced after ionisation drift towards the wire and signal is recorded for every electron approaching the wire. Thus this TRT works and the signal are obtained for every passing particle. Thus these three parts works and detect the particles.

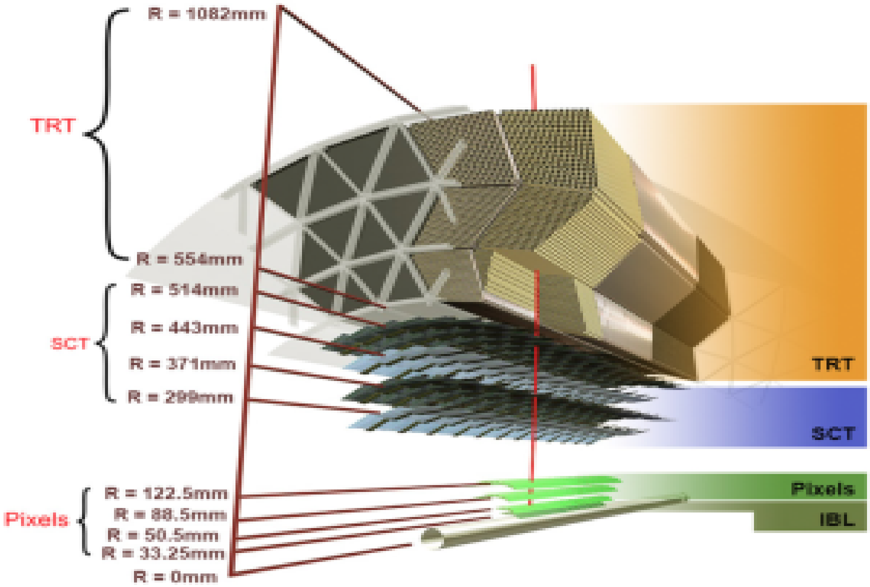


Figure 3: Layout of Inner tracking system sub-detector of ATLAS detector showing arrangement of the pixels,the semiconductor tracker (SCT) and transition radiation trackers (TRT). 17

3.2 Electromagnetic Calorimeter

This is the next subdetector which particles, after passing through, the ITS, encounters. This subdetector measures electrons, photons and other leptons. Unlike trackers, this subdetector try to stop the particles from passing through it and let them deposit all their energy over it. It is made up of thousands of lead tungstate calorimeters where particles deposits energy. It is of barrel type which surrounds the ITS. Particles mainly electrons, photons and leptons strikes the Ecal (Short hand for Electronic calorimeters), they deposits their energy on the calorimeters. Now lead tungstate is a specific type of material which is also known as scintillators i.e. they produce photons based on the amount of energy deposited on their surface.

Then these photons falls on photo-diode multipliers which on receiving scintillation light produce multiple photons thus amplifying the signal which is then converted to electrical signal by transducers and then stored in the read-out chambers. These signal are further processed and then energy of incident particles is calculated based on these electrical signals. This part of the detector measures both charged and neutral particles as it detects particles based on their energy deposition. But unlike silicon trackers, this subdetector measures particles having higher momentum with more accuracy than the particles having low momentum.

3.3 Hadronic Calorimeter

The hadronic Calorimeters (Hcal) are the next sub-detector of the ATLAS detector. It has two main parts barrel and end-caps. Barrel Hcal measures particles coming out with very low pseudo-rapidity and Endcaps Hcals measures particles coming out with high pseudo-rapidity. It's working principle is almost the same as that of Ecal. It's main purpose is to detect the hadrons. As hadrons are heavier than leptons they carry more energy as compared to leptons and thus pass through the Ecal and strikes the Hcals where they are completely blocked that is they can't go further and they deposit all of the their leftover energy there. The hadrons after striking the Hcal produce secondary showers of particles like pions, muons which after falling on scintillators present in Hcals emit photons. The no of photons emitted directly depends on the energy of particles falling on the scintillators. Then these photons falls on photo-multipliers which produce multiple photons and amplify the signal. An electrical signal is generated by transducers from these photons and stored in readout chambers for further analysis.

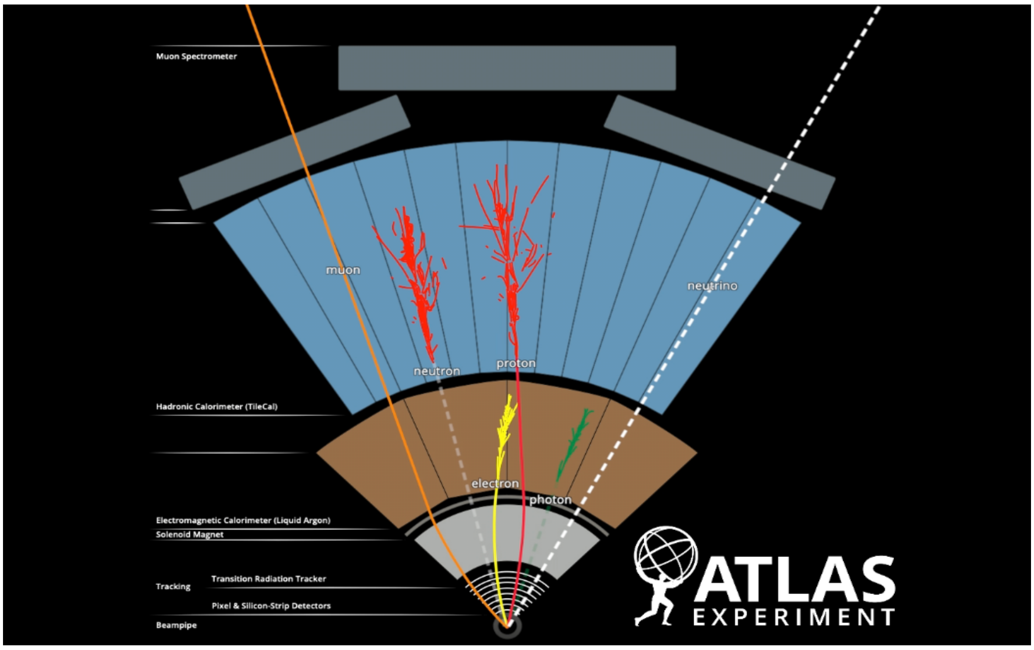


Figure 4: Slice of ATLAS detector showing propagation of different particles through each part. 18

3.4 Muon detectors/Chambers

The final subdetector where only the most energetic particles reaches is the muon detector. It is basically gas ionisation detector and works on the same principle of detection after ionisation. There is gases filled in this detector which is mostly xenon or argon or some mixture of other gases. When a particle enters this detector it collides with the gaseous atoms present there and ionises them.

This electron then under the presence of electric field starts moving towards the anode and on the way ionises further atoms. Due to this avalanche is produced and all the electrons gets accumulated at the anode. The no of electrons accumulated at the anode is proportional to the energy of the particle with which it ionised the first atom. Thus the energy, momentum ,track followed by the particle can be measured as it will keep on ionising more atoms on it's way until it itself falls on the cathode or anode depending on the charge of the particle after bending under the presence of magnetic field produced by the coils.

There are steel yokes present in the muon chamber. They are used to bend the magnetic field in the detector itself that is they make sure that the magnetic field produced by the coils remains only inside the ATLAS detector and does not go outside it. So in a way they keeps the field up to muon chambers only. Additionally they are helpful in blocking the energetic particles so that the particles looses energy and remains only in the detector, do avalanche and get detected by the detector.

4 Data Selection

After the collisions the data is obtained from the detectors. But the data obtained is in raw from. In raw form means that the data obtained directly from the detectors can't be used for analysis. This is because what detector gives is how much energy is deposited at which part of the detector or at which sub-detector. Also the data obtained from the detector is large in size. All the data can't be stored and processed in given time as the collisions keep on going on inside the detector and the data coming from the next bunch crossing (The proton beams are released in bunches inside the collision tube.These bunches have a gap in between them usually of 25 ns) is also to be stored.

So the data is to be stored within a time which depends on the spacing between two bunches of protons and the speed with which the bunches are accelerated in the accelerators. So within the available time it is not possible to store all the data. Due to this only useful data is kept and rest is not stored and useful data is processed for further analysis(Useful data here means data obtained from particles produced in primary interaction i.e. interaction between initially produced particles ot the particles produced directly from collision as they mainly contain a lot of information about physics of interest. Unuseful data is the data obtained from the particles produced in the pileup which usually are errors that ride along with particles produced in the main collisions. Pileup here is the particles coming from additional interactions except the main collision event. For e.g. interactions taking between particles of same bunch or interactions between particles of colliding beams and detector parts before collision and many more sources are there from which we obtain pile up events).

The selection of useful data in the detectors is not an easy task. A number of algorithms are used to select the useful data. The useful data/events are selected based on certain triggers. Here triggers means the condition which the events have to satisfy to be useful events otherwise the events are considered coming from pileup or underlying events and are neglected. These triggers are made depending on the analysis of data mostly obtained from the previous runs.

Some of the triggers are given here. Like for the particle to be photon coming from primary interaction it should have deposited energy nearly 4.2 +- 0.006 MeV in the electromagnetic calorimeter (Ecal short-hand for electromagnetic calorimeter) and the ratio of energy deposited by it in the Hadronic calorimeter (Hcal short-hand for the Hadronic calorimeter) to Ecal should be less than 0.5 MeV. For electron pseudo-rapidity (η) should be $\eta < 1.4442$ and $< 1.5660|\eta| < 2.5$. For muon less energy deposit in Ecal and Hcal and sum of momentum of particles around it should be very less than it's own momentum. Similarly, for the identification of other particles triggers are there.

Besides, these triggers there are also a number of techniques which are put into use to decide whether the event came from primary interaction or some other secondary interaction (Here primary interactions means the interactions between original colliding particles or interactions between particles directly produced from collisions i.e. protons in our case and the secondary interactions means the interactions taking place between the particles produced after the collisions. The primary interactions contains particles which contains information about the physics people are interested in and thus the primary events are very important for analysis). Now using the data from trackers tracks of particles can be found out. Using these tracks it can be found which particles came from primary interaction as these particles mainly come from the central part of the detector where the bunches coming from opposite directions are made to collide. So if a particle track is originating from the center of the detector that particle is most likely to arise from the primary interactions. But this technique is applicable for charged particles only as neutral particles do not leave tracks.

For neutral particles data from the calorimeters is used. Data from the calorimeters is used for identification of both charge and neutral particles. Then an algorithm known as anti-k_t algorithm is used to from the jets. Basically jets are a tool to represent the hadronic showers. This algorithm basically groups together the points where energy is mostly deposited at the calorimeters. Then using those area of the calorimeters cones are made. A jet is made from those cones and that data is selected and stored from further analysis. The anti-k_t algorithm makes cone-like circular jets. The particles coming from primary interactions are energetic while that coming from pileup contains less energy. So particles with more energy deposit more energy at the calorimeters and jets are made from these particles using anti-k_t algorithm. This algorithm is named so because it first takes into account low energy particles and then high energy particles. There are other a number of techniques which are used at the detectors for jet formation.

5 Jet reconstruction

After selecting the data carefully and after forming jets using algorithms like anti-k_t algorithm, the jets are reconstructed again. This is done because a large of collisions happens at the same time.A picture of the collisions going on in the detector is pasted in the figure 5 for having a better idea of the situation. Now from the image, it must have been clear that processing data only once to form jets is not enough. So the jets formed using the algorithms available needs to be reconstructed for getting more accurate jets. As mentioned earlier with jets we can represent hadronic showers. Jets basically contains those particles, in large amount, that are of interest for precision measurements of particles coming from primary interactions and jets are also used in searches for new particles. So jets are very important. Now for the reconstruction of jets some steps are followed. These are removal of pile-up or major sources of error, creating inputs to jet reconstruction algorithms, calibrating the resulting jets, correcting the data by matching with data obtained from simulation and obtained from the previous runs.

Now the pileup is the additional interactions that takes place along with the primary interactions. The pileup obtained from the same bunch is known as in-time pile-up. Now as it is known that collision beam came into bunches and these bunches collide to produce particles which are observed. The space between the bunches is about 25 ns. The time taken by the ATLAS detector to store the data coming from one bunch of collision is about 450 ns. Therefore in the time the detector read data of one bunch's collision about 18 bunches more collides. Due to this it is also possible that the particles from different bunch collision are mixed in the reading process by the detector. This error of measuring particles of some other collisions is known as out of time pile-up.

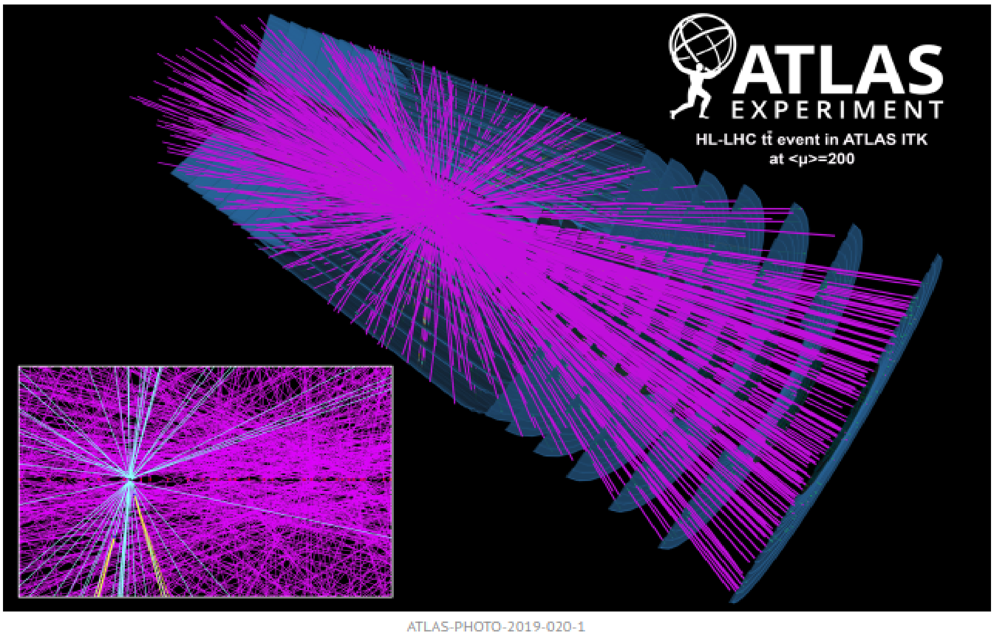


Figure 5: The image shows the no of collisions happening inside the ATLAS detector. 19

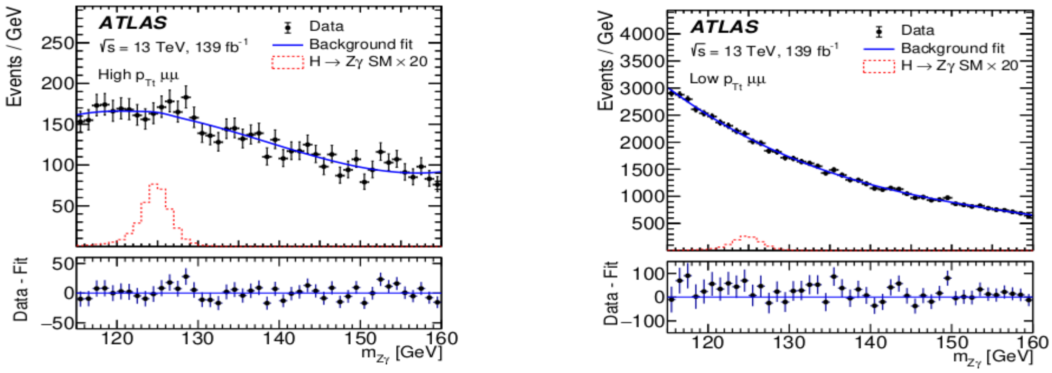
Therefore to remove these effects and make an input for jet reconstruction, information from different sub-detectors is combined. Like when the information from trackers and calorimeters are used to make jets then the jets formed are known as calo-jets. The trackers can only detect charged particles with low momentum. In contrast of it the calorimeters can detect all the particles but it can detect particles having high momentum. So if information from both sub-detectors is combined then properties of all the particles can be measured with more accuracy. First the energy deposited at the calorimeters is observed. Those cells are marked which has high deposition of energy around them.

Particles that came from primary interaction or from the QGP mostly come along that is comes side by side. So if energy is concentrated nearly around an area then it is most likely deposited by the particles produced from QGP or particles produced in the direct collisions at the detectors. So these areas are used to form the jets. Then the energy deposited at the calorimeters is matched with the tracks that are left by particles. If the energy deposited matches to a tracks available in the trackers then definitely the particles of interest traversed through the trackers and make tracks and then deposited energy in the detectors. If the track is not matching then the energy is deposited by particles produced in the secondary interactions like interactions of particles coming come QGP or interactions between the primary particles. This process of using information simultaneously from trackers and calorimeters is known as particle flow.

The particle flow suppresses the contributions coming from the pileup. Also by matching the vertices through tracks charge particles coming from pileup can also be removed. This process is known as charged hardon subtraction. But can be applied to only charged particles as neutral particles don't leave tracks in the trackers. Thus using information of both the detectors jets can be formed which will be used as inputs for reconstruction algorithm. After having the inputs for reconstruction techniques, jet calibration is done. First of all the origin of the jet inputed is corrected. The jet origin is set to the point of the hard scatter. This does not modify the energy of the jet. Then the four momentum of individual particle of the jet is corrected. Here both the direction and energy is calibrated. Then the data is matched with those of simulations and again calibrated in accord to the simulation result. Thus the reconstructed jets are obtained which are used after storing for further analysis.

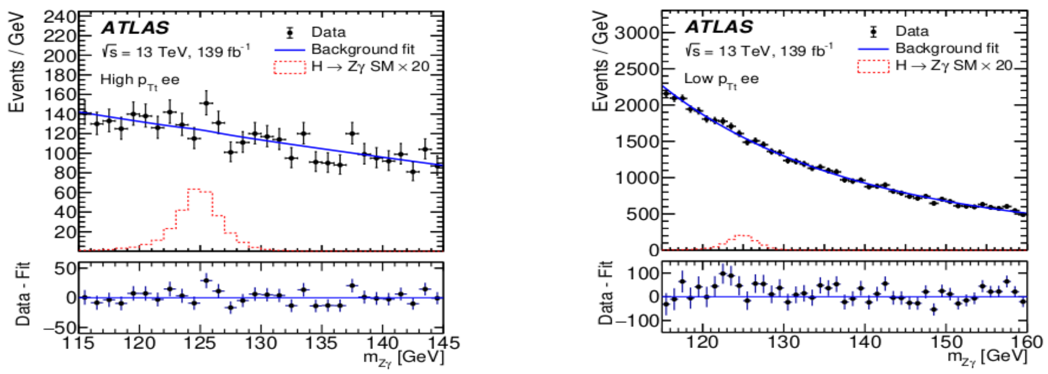
6 Result

After selecting the events, only useful data is there and it can be said that the most of the background i.e. events coming from pileup have been been removed. Basically we have removed the error on large scale. Now in the channel higgs decaying into a Z boson and photon, Z boson can further decay into a pair of muon and anti-muon or into a pair of electron and positron.



(a) Events with high p_T carried by muon pair (b) Events with low p_T carried by muon pair

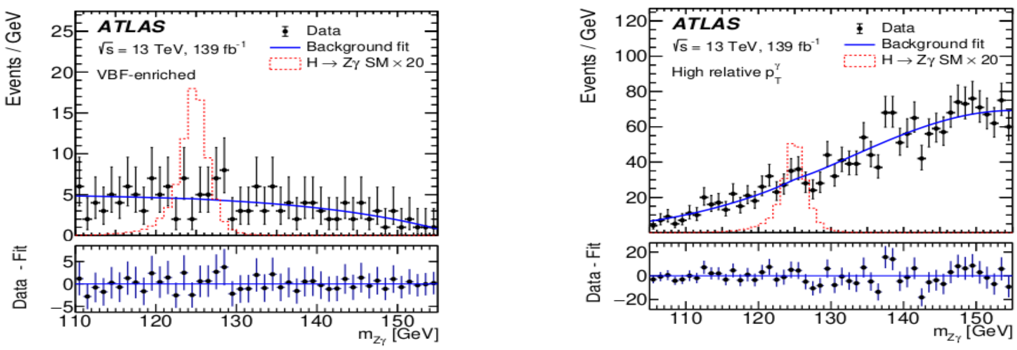
Figure 6: Figure (a) has the higgs mass spectrum obtained obtained from the events in which the muon pair was having high transverse momentum and figure (b) the events in which the muon pair was having low transverse momentum. The X axis contains mass of higgs and Y axis represents the number of events per GeV.The black points shows data. The blue bar is fitted curve. 20



(a) Events with high p_T carried by electron pair (b) Events with low p_T carried by electron pair

Figure 7: Figure (a) has the higgs mass spectrum obtained obtained from the events in which the electron pair was having high transverse momentum and figure (b) the events in which the electron pair was having low transverse momentum.The X axis contains mass of higgs and Y axis represents the number of events per GeV. The black points shows data. The blue bar is fitted curve. 21

In these possibilities there will also be chances when Z boson is having most of the energy and the photon have less energy or photon having high energy and the decay products of Z boson having less energy. Now what is done is that the energy and momenta of all these decay products in the channel like photon ,muon,anti-muon etc have been obtained from the detector. That is the four vector of all the particles are obtained from the detector that are



(a) Vector boson enriched

(b) High relative p_T^γ

Figure 8: Figure (a) has the higgs mass spectrum obtained obtained from the events in which the vector boson number dominates and figure (b) the events in which photons come out with higher energy relative to Z boson.The X axis contains mass of higgs and Y axis represents the number of events per GeV. The black points shows data.The blue bar is fitted curve. 22

decay products of the higgs via the channel higgs decaying into Z boson and photon. Then the four vector of these decay product is added to get a new four vector. This four vector is the four vector of the higgs. From the four vector of the higgs it's mass can be found out using relativistic mass energy relations. This mass is plotted with respect to no of events containing that mass. The plots are given in figure 6, 7, 8.

Now there are potential sources of error in this analysis. This analysis is done on the particles obtained from the detector. Like for the case higgs decaying into photon and Z boson and Z boson further decaying into muon and anti-muon, the four vector of all the muons and anti-muons detected by the detector is taken into account. That is there will be muons and anti-muons coming from the decay of Z boson which came from the higgs decay and there are muons and anti-muons which will be obtained from decay of other particles or coming from other interactions of particles. These muons and anti-muons will lead to error and because of these muons and anti-muons the mass of higgs is supposed to come out in a range depending on the energy of moun and anti-muon which are used to form the pairs. In simple words there can be wrong selection of muon and anti-muon which could lead to error.

Also it is observed that the decay of higgs contains missing energy (Description of missing energy is given in the introduction). That is when correct pair of muon and anti-muons and right photon is selected and then the energy of these particles is added it turns out that the sum is not equal to the energy of higgs. Some energy is missing and how to take into account that energy is still not known. So this missing energy also known as Missing Transverse Energy (MET) at the detectors is main source of error, responsible for wrong calculation of higgs mass. Due to all these possibilities the mass of higgs would vary in a range.

To take into account the missing transverse and the effects of wrong selection of muon and anti-muon pairs only those muons are used which came out opposite to each other that is which came out at angle π between them. Same for the selection of photon.The photon which came out at angle π between photon and Z boson obtained from the combined four vector of muon and anti-muon. Since the particle, in the described case, came out at angle of π then there is no possibility of missing energy and selection of wrong muon and antimuon.Though there would still be space for error but the case now is much better. Due to this selection a peak around 125 GeV is obtained which means the mass of higgs is around 125 GeV. The figure 9 contains the plot for all the events that is all the decay channel taken is taken into account. Like the case in which Z boson further decayed into a pair of mouns and anti-muons, pair of electron

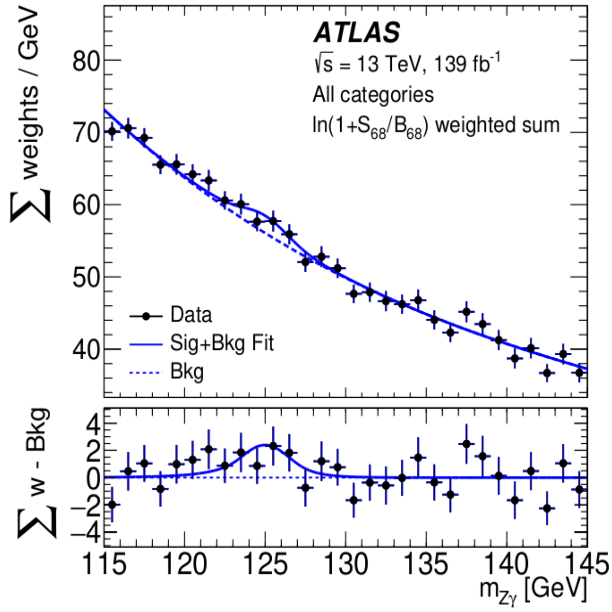


Figure 9: The x axis contains the mass obtained from the Z boson and photon combination. The Y axis contains the weighted sum of events per GeV. The black points shows data.The blue bar is fitted curve.Events weighted by the formula $\log(1+\frac{S_{68}}{B_{68}})$. Here S_{68} represents expected signal and B_{68} represents the expected background events containing 68% of the total expected signal. 23

and positron and rest of all channels. Again the peak for selected events that is events left after removing the error contributions from the events discussed above, is around at 125 GeV.

7 Conclusion

The method for the finding out the higgs boson was studied as provided in the paper [**1**]. Using this method mass of the higgs was found with an upper limit to confidence level of 95% having mass around 125 GeV. The observed data was also consistent with the expectations that were predicted theoretically. The mass of higgs was matching with the predictions of theory.

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