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Project proposal for the investigation of $q\overline{q} \rightarrow HZ/HW \rightarrow \mu^+\mu^- q\overline{q}$ channel at the ATLAS detector at the LHC

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Abstract

The Large Hadron Collider is currently on its second run at $\sqrt{13}TeV$ center of mass energy in order to measure the Higgs boson properties. This proposal describes what is currently known about the Higgs boson and puts forward the idea to investigate the specific production and decay channel $q\overline{q} \rightarrow HZ/HW \rightarrow \mu^+\mu^- q\overline{q}$. The method of simulating pp collision data, comparing this data with actual data from ATLAS and a timetable for the project are also discussed.

1 Background

1.1 Higgs Boson

The Higgs boson is a particle which was first detected at CERN in 2012 [2] via proton-proton collisions at the large hadron collider. Since its first detection at the ATLAS and CMS detectors the Higgs boson properties and alternative decay modes have continuously been investigated. Current measurements show the Higgs boson to have no electric charge, colour charge or spin with a short lifetime.The Higgs boson is also believed to couple to the mass of the particle produced and therefore the probability of the Higgs boson decaying into specific particles depend on their mass. The current mass of the Higgs boson has been measured as $125.09 \pm 0.21(stat) \pm 0.11(syst) GeV$[3]

1.2 Higgs Boson Production

The Higgs boson can be produced via several different production channels. The production channels used to estimate the Higgs boson mass[2], are shown in figure 1.

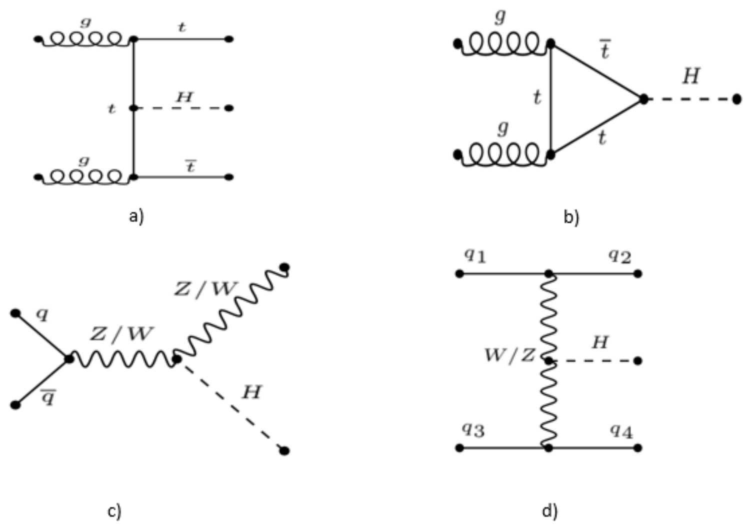

Figure 1: Higgs boson production channels, a) is associated production of $t\bar{t}$ pair, b) is gluon fusion, c) is associated production of a vector boson and d) is vector boson fusion [2][6].

Each of these production channels have an associated cross section which indicated the likelihood of an event occurring. The number of Higgs boson events is low compared to other events occurring therefore a large background is expected.

1.3 Higgs Boson Decay

The Higgs boson has been observed, at the CMS and ATLAS experiment, via several different decay channels. The requirement for a confirmed detection is a significance of 5 standard deviations. Several decay channels currently being investigated are shown in figure 2.

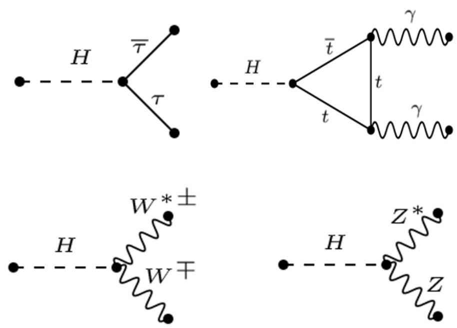

Figure 2: Higgs boson decay channels, the double photon decay can also be mediated by W bosons [3][4][6].

Currently $H \to \tau\bar{\tau}$ has a significance of 3.7σ [4], while the other decay channels have all been confirmed. The particles produced decay into varying particle detected using the ATLAS detector. The momentum and energy of these produced particles are measured and used to reconstruct the interaction in order to measure the Higgs boson properties as well as how it decays.

1.4 Atlas Experiment[1]

The ATLAS detector consists of several sections. The inner part of the detector consists of trackers designed to track the motion of charged particles.The innermost part is a three layered, silicon pixel detector. The next part consists of a semi-conductor tracker made up of eight layers of silicon strips. The third layer consists of a transitional radiation tracker which employ on the use of straw detectors. Surrounding the inner detector is a solenoid producing a 2T magnetic field which facilitates the bending of charged particles within the inner detector.
The electromagnetic calorimeter and hadronic calorimeters are positioned just outside of the solenoid. Both of these are sampling calorimeters which work by initiating electron showers and then measuring the subsequent energy deposited. Outside of these calorimeters lies the muon detector. This is a large part of the detector which identifies and measures the momentum of muons passing through it. Interwoven with the muon detector are 8 toroidal magnets which produce a non uniform magnetic field throughout the detector. figure 3 shows a cross section of the detector.

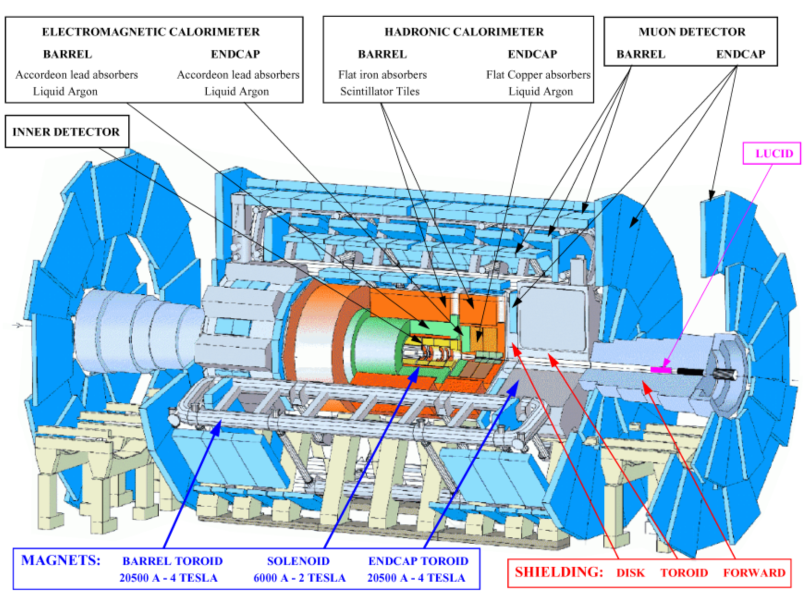

Figure 3: ATLAS detector cross section (http://hedberg.web.cern.ch/hedberg/home/atlas/atlas.html).

2 Motivations

The aim of the proposed project is to investigate an unobserved Higgs boson to $\mu^+\mu^-$ channel, shown in figure 4. This particular channel has not been looked at. The Higgs boson decay within this channel is similar to the Higgs boson to $\tau^+\tau^-$ decay, shown in figure 2. The ratio of the $\mu^+\mu^-$ and $\tau^+\tau^-$ branching fractions is given in equation 1.

$$\frac{Br(H \to \tau^+\tau^-)}{Br(H \to \mu^+\mu^-)} = \frac{6.32 * 10^{-2}}{2.19 * 10^{-4}} \approx 289 \tag{1}$$

The branching fractions were taken from [5]. The difference in branching ratio is due to the higher mass of the tau lepton.The consequence of this is that the Higgs boson, which couples to mass, has a higher chance of decaying to $\tau^+\tau^-$ which has been observed; rather than the $\mu^+\mu^-$ unobserved decay which is the proposed decay investigated by this project.

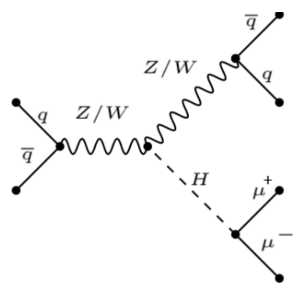

Figure 4: Higgs boson decay into $\mu^+\mu^-$ pair with associated production of a $q\overline{q}$ pair[6]

Simulated collision events for this decay will be used to predict the integrated luminosity required by ATLAS and calculated to what significance this decay will be observed within the current LHC run.The simulated events will also be compared to data from the ATLAS experiment in order to see any discrepancy between the Standard Model simulation and actual measurements and thus observe any indication of physics beyond the Standard Model. Within this analysis as much of the background as possible will be reduced.

3 Method

3.1 Simulated Data

In order to achieve the aims outlined in section 2 new computer packages will need to be used. These packages are based in ROOT software, which can be used for data analysis. Using Monte Carlo software both the background and signal events can be generated for proton-proton collision events. Once this data is generated it is put through Geant4, which is a detector simulator. Geant4 alters the generated events into what would be seen by the ATLAS detector, along with associated uncertainties. In the proposed channel the muons are directly observed in the muon detector and the $q\overline{q}$ product is seen as jets of hadrons. The tagging of these hadronic jets will need to be investigated. When this is complete the background can be studied and cut by defining selection regions and normalising the background against the control region.

3.2 Results Analysis

By extracting background and signal Monte Carlo Standard Model predictions within the signal region a significant level can be calculated. A crude way of calculating this is to use equation 2.

$$Significance = \frac{S_{MC}}{\sqrt{b}} \tag{2}$$

Where S_{MC} is the Monte Carlo signal and b is the background. In reality a statistical analysis will be performed to calculate the correct significance. Until this point in the project the actual data will not be looked at to avoid bias when defining signal regions. The significance for the actual data can be calculated by using S_{data} in equation 2, analysed and compared with the significance for the Monte Carlo data.The actual branching ratio can also be compared with the Standard Model branching ratio for this decay mode using equation 3.

$$R = \frac{Br(SM)}{Br(Data)} \tag{3}$$

if the value of R is equal to 1 then the data is consistent with the Standard Model. However if the value is not equal to 1 then physics is occurring beyond the Standard Model.
In order to analyse the particle detections the integrated luminosity is required. In the first run of the large hadron collider approximately $3fb^{-1}$ of data was collected. During the current run $100fb^{-1}$ is planned. Using the integrated luminosity, along with branching fractions and cross sections, an estimate of the number of events can be calculated using equation 4.

$$n_{events} = \epsilon * L_{int} * Br(H \to \mu^+\mu^-) * [\sigma(pp \to HW) * Br(W \to q\bar{q}) + \sigma(pp \to HZ) * Br(Z \to q\bar{q})] \tag{4}$$

Where ϵ is the detector efficiency, assumed to be 1 in this case, and L_{int} is the integrated luminosity.The values for cross section and branching fractions assume a Higgs boson mass of approximately $125GeV$ and the LHC is operating at $\sqrt{s} = 13TeV$. With an integrated luminosity of $100fb^{-1}$ and a detector efficiency of 1 the number of events is ≈ 34, using the relevant cross sections and branching fractions[5].

4 Timetable

In order to meet project deadlines and complete the project efficiently a Gantt chart has been written and as shown in table 1. The chart is subject to change if problems arise during completion of specific sections which requires additional time. New areas of research may also become apparent which require additional time to complete.

Autumn Term												
Week beginning	**28/9/15**	**5/10/15**	**12/10/15**	**19/10/15**	**26/10/15**	**2/11/15**	**9/11/15**	**16/11/15**	**23/11/15**	**30/11/15**	**7/12/15**	**Winter break**
Project deadlines:					Proposal						Poster	
Reading (scientific papers)												
Write project proposal												
Learn to use computer packages												
Event background study												
Create project poster												
Spring Term												
Week beginning:	**11/1/16**	**18/1/16**	**25/1/16**	**1/2/16**	**8/2/16**	**15/2/16**	**22/2/16**	**29/2/16**	**7/3/16**	**14/3/16**	**21/3/16**	**Spring break**
Project deadlines:										Seminar	Final Report, notebook	
Event background study												
Determining optical cuts												
Extract background prediciton												
Actual data comparison												
Create final plots												
Write final report												
Create seminar presentation												
Summer Term												
Week Beginning:	**25/5/16**											
Project deadlines:	Viva											

Table 1: Gantt chart showing the initial timetable for the project

References

[1] ATLAS Collaboration, May 1999, ATLAS detector and physics performance : Technical Design Report, 1.

[2] ATLAS Collaboration, July 2012, Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC.

[3] ATLAS and CMS collaboration, March 2015, Combined Measurement of the Higgs Mass in pp Collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS and CMS Experiments.

[4] CMS collaboration, May 2014, for the 125GeV Higgs decaying to a pair of τ leptons.

[5] LHC Higgs boson Cross Section Working Group, S. Heinemeier, C. Mariotti, G. Passarino, R. Tanaka (Eds.), Handbook of LHC Higgs Cross Sections: 3. Higgs Properties, CERN–2013–004 (CERN, Geneva, 2013), DOI: 10.5170/CERN–2013–004

[6] Alec Aivazis,Feynman computer package, used to draw Feynman diagrams.