Reconstruction of $H \to llll$ decay analysis from Atlas at 10 fb^{-1}

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I. THE TASK

In this report we will look at the decay of Higgs into 4 leptons via $ZZ^{(*)}$. To analyse this final state we will use the Atlas Open Data dataset of about $10 fb^{-1}$. Here we will try to rediscover the Higgs boson. To do this we have to do a so called event selection, as there simply is too much data too look at. We also have to split the 4 leptons into two dileptons, as the invariant mass will help indicate if we have found the Higgs or not. We can either have one Z boson off shell and one on shell, or both on shell, given enough energy. The on shell Z boson dilepton pair will most likely be the pair with invariant mass closest to the Z boson, thus this will be our method to separate the dileptons. The Higgs boson can be created in various ways, as shown in the figure below.

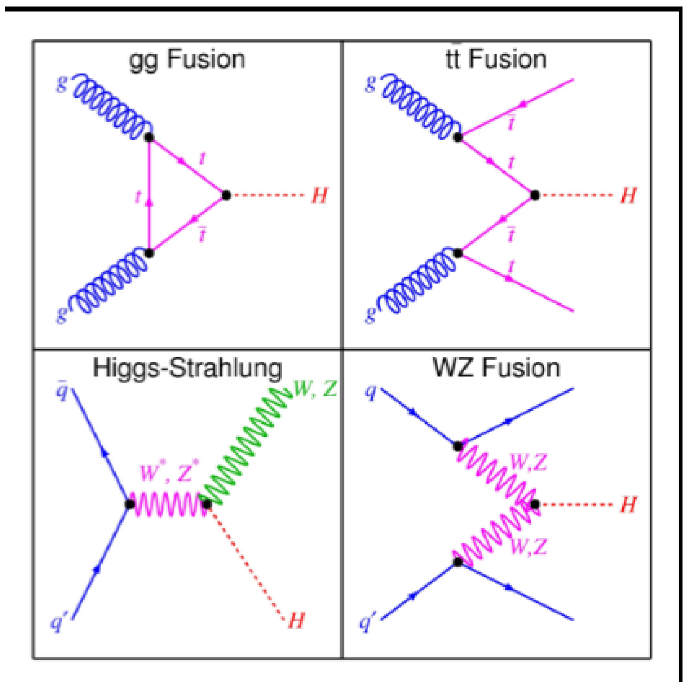


Figure 1: Higgs production at the LHC

In figure 1 we see four ways of Higgs production from proton-proton collision. Here we see some of the challenges with detecting Higgs,

A. Event selection and dilepton selection

1. Event selection

In order to filter the data, we do so called cuts. The cuts depend on what you want to research, but since we are looking at four lepton final state for the decay of the Higgs, we first have to ensure that the events we look at actually have four leptons and that they in total have zero charge. This is because we are looking at the channel where we have $H \to ZZ^{(*)} \to l^+l^-l^+l^-$, so we have a electrically neutral particle, in the start, and need a electrically neutral final state to correspond. Then, we have three possible final states that are of interest. all though there technically are 3 families of leptons, the electrons, muons and taus, the tau have decay channels that give both quarks and leptons, and so we tend to classify them as not leptons. We also do not consider neutrinos here, as they are virtually impossible to detect, and should not arise from Z decay into two leptons anyway. Our three possibilities are then either 4 electrons or 4 muons, or two electrons and two muons. Thus we check that only events that uphold this criterion passes.

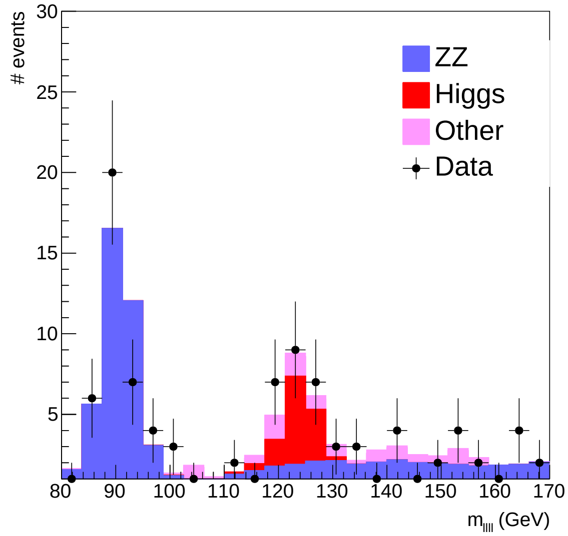
After the initial event selection we have cuts that gives us "good leptons". These cuts are the same that was done in this ATLAS article. First we require the absolute vaue of the sudo rapidity of the lepton to be less than 2.47 for electrons and less than 2.5 for muons. We further exclude all events that have absolute value of sudo rapidity in the interval $[1.37, 1.52]$. The leptons in ROOT are listed in descending order of transverse momentum. Here we require the four leptons have transverse momentum larger than the following four thresholds, 25, 15, 10, 7 GeV. Then we also put a cut on the track associated with the signal lepton compared to the primary vertex, in other words, we require that $\min z_0 + \sin(\theta) < 0.5mm$, where θ is the polar angle of the track. The last cut we impose is one the calorimeter and track isolation, $etcone20 < 0.15$ and $p_T cone30 < 0.15$, for the lepton with the highest transverse momentum, and less than 0.3 for the remaining leptons.

2. *Dilepton selection*

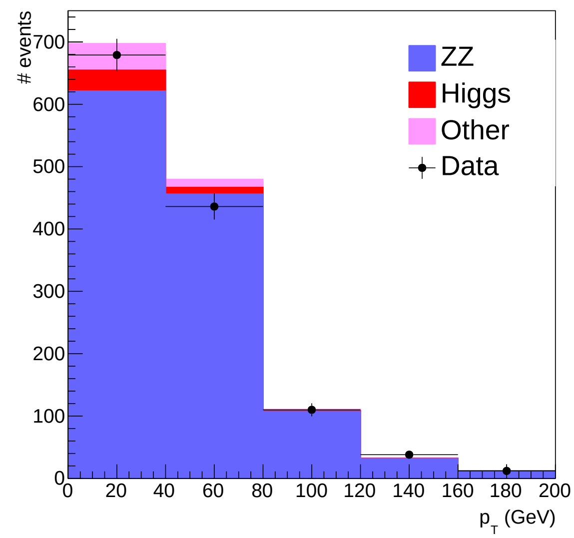
As mentioned above, we have three different possible final states for the Higgs decay. To select the proper dilepton pairs we choose the first dilepton to be the combo of leptons to have the closest mass to the Z boson, and thus giving us the other pair as the remaining two leptons. This plays out somewhat different depending on what final state we have. Lets say we have two muons and two electrons. We first have to check which is which, and then compute the mass difference. If the two electrons are closer to the Z boson mass, then they are the first dilepton pair, and vice versa. In the case we have four leptons of same type, i.e four electrons or four muons however, we need further selection. Since we removed the events where the sum of the charge is not 0, we know we have pairs with different charge. We then check one of the leptons against the other three for equal charge and make the correct combinations of pairs. With the events with only one lepton type, we first need to find which two that have the same charge, and create all the other possible combos that exclude the pairs with similar charge. We then find the combination with mass closest to the Z boson mass, and assign that as the first dilepton, and the remaining two leptons thus is the other dilepton pair.

B. The results

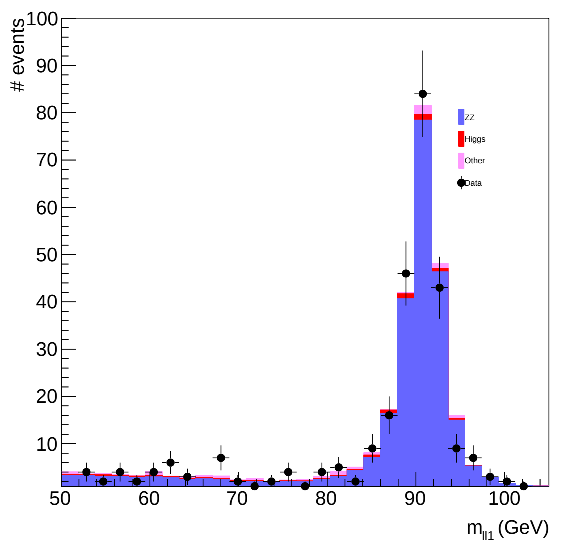
The histograms compared to in this section can be found here, specifically on page 20-21. It is worth mentioning that the Monte Carlo data was lacking certain diagrams that contribute to the background. To compensate for this we multiply the weights of the background with about 1.3, which correct for the missing diagrams.



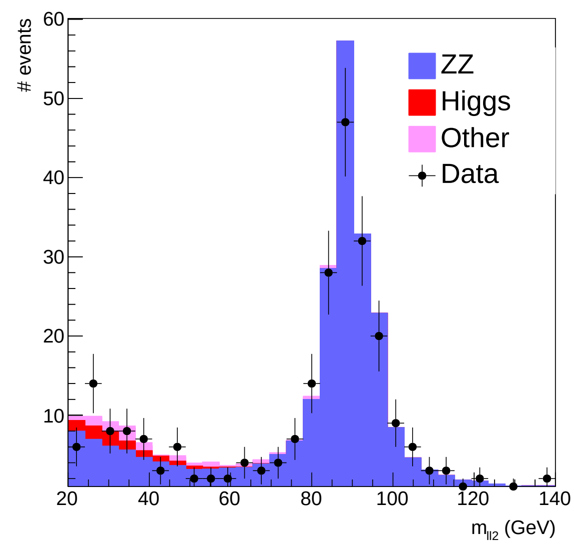
(a) Histogram showing the invariant mass of the four leptons



(b) Histogram showing the transverse momentum of the four leptons



(c) Invariant mass of the first dilepton pair



(d) Invariant mass of the second dilepton pair

Figure 2: Histograms of the 4 lepton state using ATLAS open data. First histogram shows the 4 lepton invariant mass, second histogram shows transverse momentum of the four leptons, third histogram shows invariant mass of first dilepton, and last histogram shows the invariant mass of the other dilepton.

1. 4 lepton invariant mass

In this section we will discuss and compare our histogram of 4 lepton invariant mass to the 4 lepton invariant mass shown on page 21 in the article linked to in the results section. We see here that there is very good accordance with the histogram from the article. There is a difference in that all other contributions than diboson is added on top instead of at the bottom of the bins.

2. p_T

Here we see good accordance with the plot from the article. There is some excess background in our histograms, which could be due to the fact that we corrected all the weights with the missing factor, but it in fact should only have been updated for the diboson channel. It could also be duo to some cuts that are either not taken into account or simply not working.

3. Dilepton invariant mass histograms

Here we have a bit worse accordance with the article, but still within reasonable results. We see that the background and data correspond well together, which would indicate that the selection process implemented overcount some as the first dilepton and not the second dilepton. This is shown as the first dilepton has a bit too many counts in the biggest bins, while the second dilepton histogram has a bit too few counts. The general shape of the histograms are however kept. There could also be a problem with the cuts, that some either are not implemented correctly, or not working properly, however this is not too likely as it would have shown in the p_T and 4 lepton invariant mass histograms.

4. Scaling

As mentioned above, the results have been produced using scaling, to compensate for the missing channel. Originally, the 4 lepton invariant mass looked like the figure below:

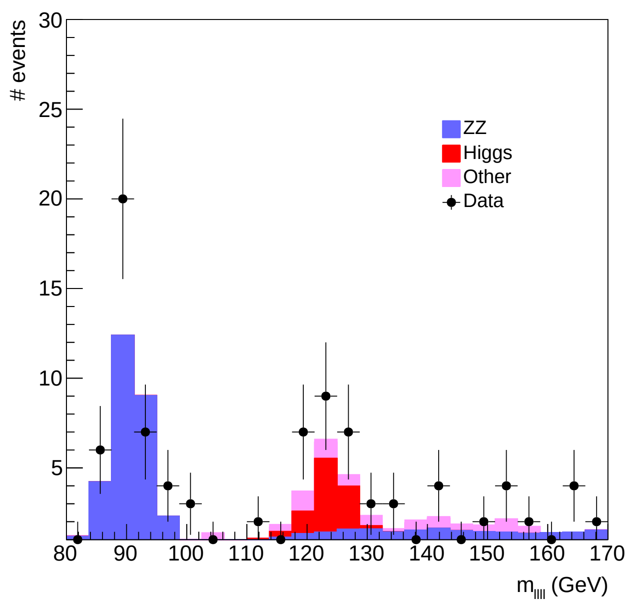


Figure 3: Four lepton invariant mass without scaling.

If we compare this histogram to the one in figure 2a we see here that there are some background missing. It would appear that a diboson channel is missing, and as explained above, we compensate for this by multiplying the weights by around 1.3.

C. Feynman diagrams for the 4 lepton final state

In this project we look at the diboson into 4 lepton final state decay for Higgs. Thus, the Feynman diagram gives us really three possibilities.

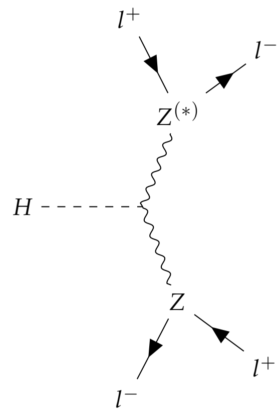


Figure 4: Four lepton final state of Higgs decay to two Z bosons

In figure **??** we have as mentioned above 3 possibilities. Either all four leptons are electrons, all four leptons are muons, or two of them are electrons and two of them are muons.