Draft version November 11, 2019
Typeset using LaTeX default style in AASTeX63

QCD and Higgs Data Analysis

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(Revised November 11, 2019)

ABSTRACT

The motivation for analyzing the following data is to attempt to discover if the interactions of the Higgs boson align with what is predicted from the Standard Model. The Standard Model predicts that about 60% of Higgs decay into b-quark pairs, meaning that they decay into a pair consisting of a bottom quark and anti-bottom quark. looking into the data from the LHC and ATLAS would allow us to see if the Higgs boson's natural width-the range of masses it could have- is described by the Standard Model or not. The width of the Higgs boson arises from the uncertainty principle $2\Delta E\Delta t = \hbar$, thus the natural width of the Higgs tells us about how it interacts with other particles(some of which we may not even know exist yet).

1. LOOKING AT THE DATA

The goal is to understand the QCD and Higgs data provided. The first thing I decided to do was make a histogram of the QCD and Higgs data so I could identify any trends in the data and then I also plotted them on top of each other so I could simultaneously view any discrepancies between the two data sets.

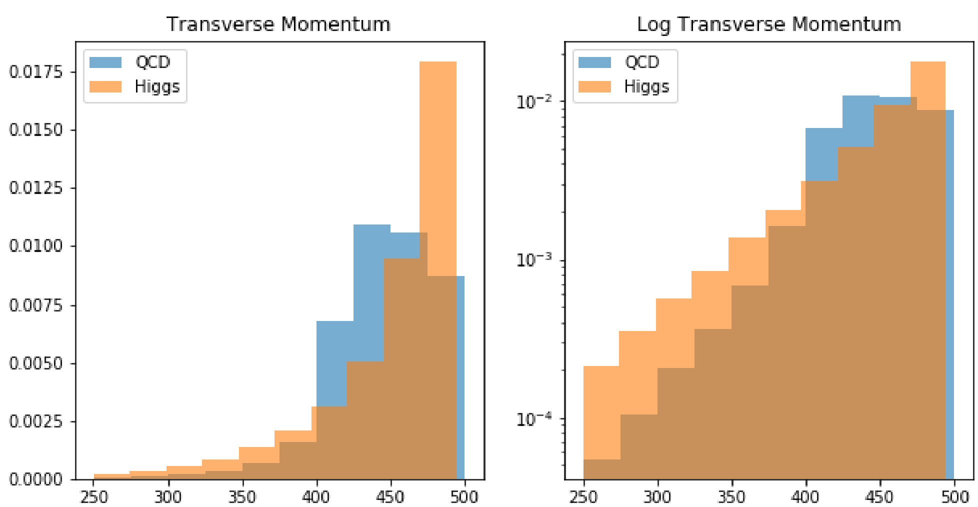

Figure 1. Histogram of Transverse Momentum Data

Looking into the data of the transverse momentum(Fig.1) we can see that there appears to be a similar trend between the two data sets such that they have more data at higher transverse momentum. This trend would make sense because in order to detect the physics of the Higgs boson, namely the b-quark pair decay, there needs to be a large amount of transverse momentum. Higgs boson is produced in association with a W or Z boson decaying to leptons, and recoiling with a large transverse momentum, in order to suppress the overwhelming irreducible background from quantum chromodynamics (QCD) multijet production of b quarks.[REF Inlcu.] The transverse momentum should be above 450 GeV to lessen the effect of the background caused by QCD multijet production. We can see in the data that the majority of data has a transverse momentum > 450 GeV. These numbers make sense in the context of the experiment.

The next part of the data I became immediately interested in was the azimuthal angle since this angle describe the direction from the beam-line that the decay products propagated. ATLAS has the ability to detect nearly the entire solid angle around the collision point.[REF ATLAS] This means that even before inspecting the histogram we would expect to see values between $-\pi$ and π on the x-axis and for each value to have approximately equal probability of occurring in the data sets.

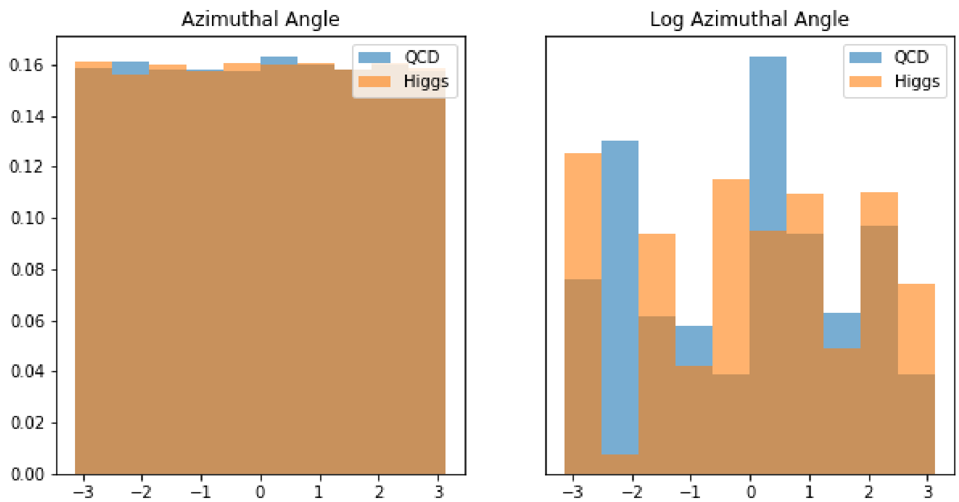

Figure 2. Histogram of Azimuthal Angle Data.

The plot on the left is a log scale of the probability, but since the two data sets are so close to the same values the log scale goes extremely small and caused an error with matplotlib where it would not display the y axis ticks. With this in mind it is safe to say that the seemingly large discrepancies in the log plot are actually extremely small and can be ignored(This is more intuitive just looking at the normal plot). I predicted that physically it would make sense that if the ATLAS detector could measure the entire solid angle around the collision point then we should see values between $-\pi$ and π at all equal probability. This is exactly what we see in the data. As a side note, it is possible that the small variations seen in the log plot could be due to a gap in the detector around -2 radians, but since the effect is small I doubt that this is the case. Regardless, physically each angle of detection should be equally likely and that is what is shown in the data,

The next parameter I was interested in exploring was the mass data from both the Higgs and QCD data. The natural width of the Higgs boson is based upon the width of the measurement of its mass. This means that before looking at the mass data we would expect the QCD data to have a wider spread due to the multi-jet production of b-quarks. The Higgs data may also show the upper or lower limit of the mass of the Higgs. Looking at Fig.3 we can see some interesting features about the invariant mass measurements. Notably, it is apparent that in the Higgs data that the mass peaks in counts at around 125 GeV/c^2. The Higgs data also shows a tail to the left of the large mass peak, but by inspection of the log plots this tail is about an order of magnitude less than the QCD data and around two orders of magnitude less than the peak. Interpreting the data, this would mean that the Higgs data suggest that the mass of the Higgs boson is about 125 GeV/c^2 with an acceptance greater than 50%. This acceptance percentage comes from the signal acceptance for the first reconstruction step where the Higgs boson candidate is reconstructed as a large-R jet which depends strongly on its transverse momentum. The angular separation between Higgs boson decay products can be approximated as $\Delta R \approx \frac{2m_{Higgs}}{p_T}$. Therefore, in most of the cases the Higgs boson decay products will fall within a single large-R jet with a radius parameter of R = 1.0 if the Higgs boson transverse momentum is at least 250 GeV. The signal acceptance is determined as the fraction of Higgs bosons in simulation which are reconstructed and labelled as a Higgs-jet. Only Higgs bosons with transverse momentum > 250 GeV, $|\eta| < 2.0$, and associated b-hadrons from its decay that have transverse momentum > 5 GeV and $|\eta| < 2.5$ are considered. The Higgs boson acceptance is around 50% at 250 GeV, where the jet p_T resolution have a significant impact as well, and increases to 95% for transverse momenta above 750 GeV.[ATLAS] Since the transverse momentum of the data set is above 250 GeV and below 750 GeV we know we have an acceptance between 50% and 95%.

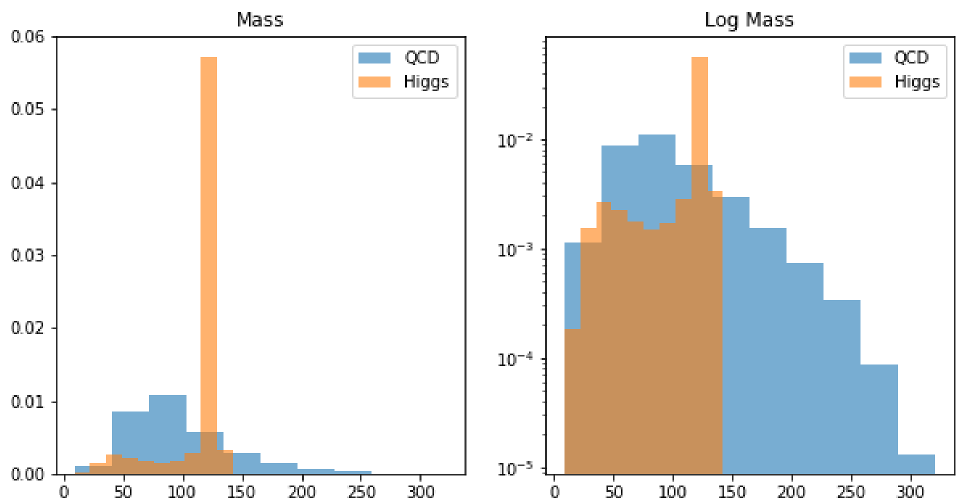

Figure 3. Histogram of Mass Data

The last histogram I was interested in exploring was the η data from the Higgs and the QCD data sets. This data is the pseudorapidity which is defined as

$$\eta = -ln\left(\tan\left(\frac{\theta}{2}\right)\right) \tag{1}$$

where theta is the angle relative the x-axis that points towards the center of the LHC ring. Pseudorapidity essentially tells us the angle of the decay particle relative the beam axis. This measurement also happens to be one of the most involved out of the experiment looking for information on the Higgs boson. Different detectors are used to cover different ranges of pseudorapidity. The ATLAS detectors cover $|\eta| < 4.9$. The calorimeter system covers the pseudorapidity range $|\eta| < 4.9$. Within the region $|\eta| < 3.2$, electromagnetic calorimetry is provided by barrel and endcap high-granularity lead/liquid-argon (LAr) calorimeters, with an additional thin LAr presampler covering $|\eta| < 1.8$ to correct for energy loss in material upstream of the calorimeters. The solid angle coverage is completed with calorimeter modules optimised for electromagnetic and hadronic measurements respectively.[ATLAS]

The muon spectrometer (MS) comprises separate triggering and high-precision tracking chambers measuring the deflection of muons in a magnetic field generated by superconducting air-core toroids. The precision chamber system covers the region $|\eta| < 2.7$ with three layers of monitored drift tubes, complemented by cathode strip chambers in the forward region, where the background is highest. The muon trigger system covers the range $|\eta| < 2.7$ with resistive plate chambers in the barrel, and thin gap chambers in the endcap regions.[ATLAS]

With these calorimeters in mind while looking at the data we would expect to see a pseudorapidity between ± 4.9. However, it is predicted that the Higgs boson decay into a b-quark pair at transverse momentum around 450 GeV should have a pseudorapidity of ± 2.5.[Inclu ref]

From this histogram in Fig.4 we can see that the pseudorapidity has a larger spread for the QCD data than the Higgs data. This makes sense because the detectors are capable of detecting in the ± 4.9 range, but the Higgs boson should have effects in the ± 2.5 range. The Higgs data essentially has a Gaussian distribution with a center of 0 and a 3σ approximately equal to 2.5. In the figures at the end of this paper are histograms of the other parameters of the experiment. We can see variations between the QCD and Higgs data on ee2,ee3,d2, and angularity as the width of the distribution of Higgs data is smaller but centered around the same value as the QCD data, meaning the Higgs has a specific visible effect in these parameters. T1, t32 correspond to the QCD data have a smaller width that the Higgs

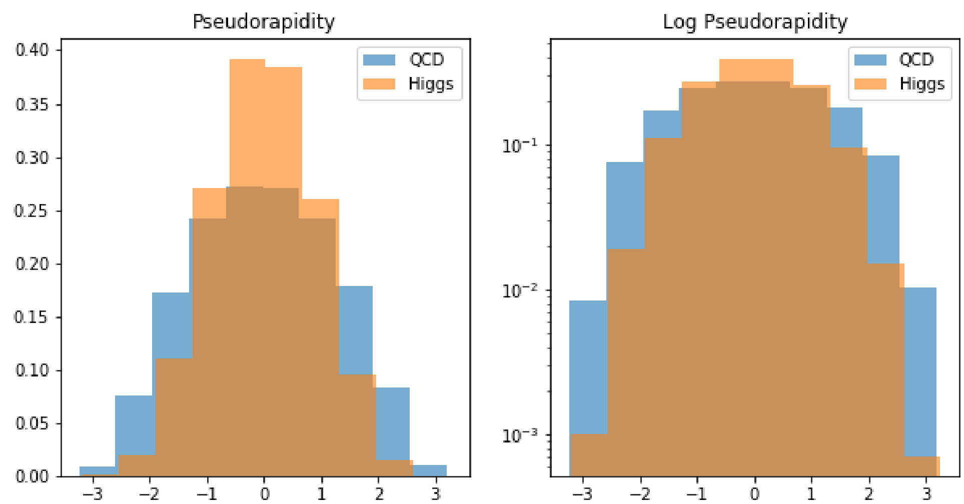

Figure 4. Histogram of pseudorapidity Data

data meaning the QCD data has a specific visible effect in these parameters. The rest of the histograms correspond to differences in centers for the Higgs and QCD data meaning they have different expected effects that shift the mean of their respective probability density functions.ee2 and ee3 are the 2- and 3-point ECF ratios, respectively, which are energy correlation functions. D2 is the ratio between ee3 and ee2, called the 3- to 2-point ECF ratio. The equations associated with these are as follows:

$$\Delta R = \sqrt{\eta^2 + \phi^2} \tag{2}$$

$$ee2 = \sum p_{T,i} p_{T,j} \Delta R_{i,j} \frac{1}{p_{T,J}^2} \tag{3}$$

$$ee2 = \sum p_{T,i} p_{T,j} p_{T,k} \Delta R_{i,j} \Delta R_{i,k} \Delta R_{j,k} \frac{1}{p_{T,J}^3} \tag{4}$$

$$D2 = \frac{ee3}{ee2} \tag{5}$$

In addition to these relations, t1, t2, t3, t32, t21 all correspond to the sub-jets that are produced, and KtΔR correspond to the distance between two sub-jets within a single jet.

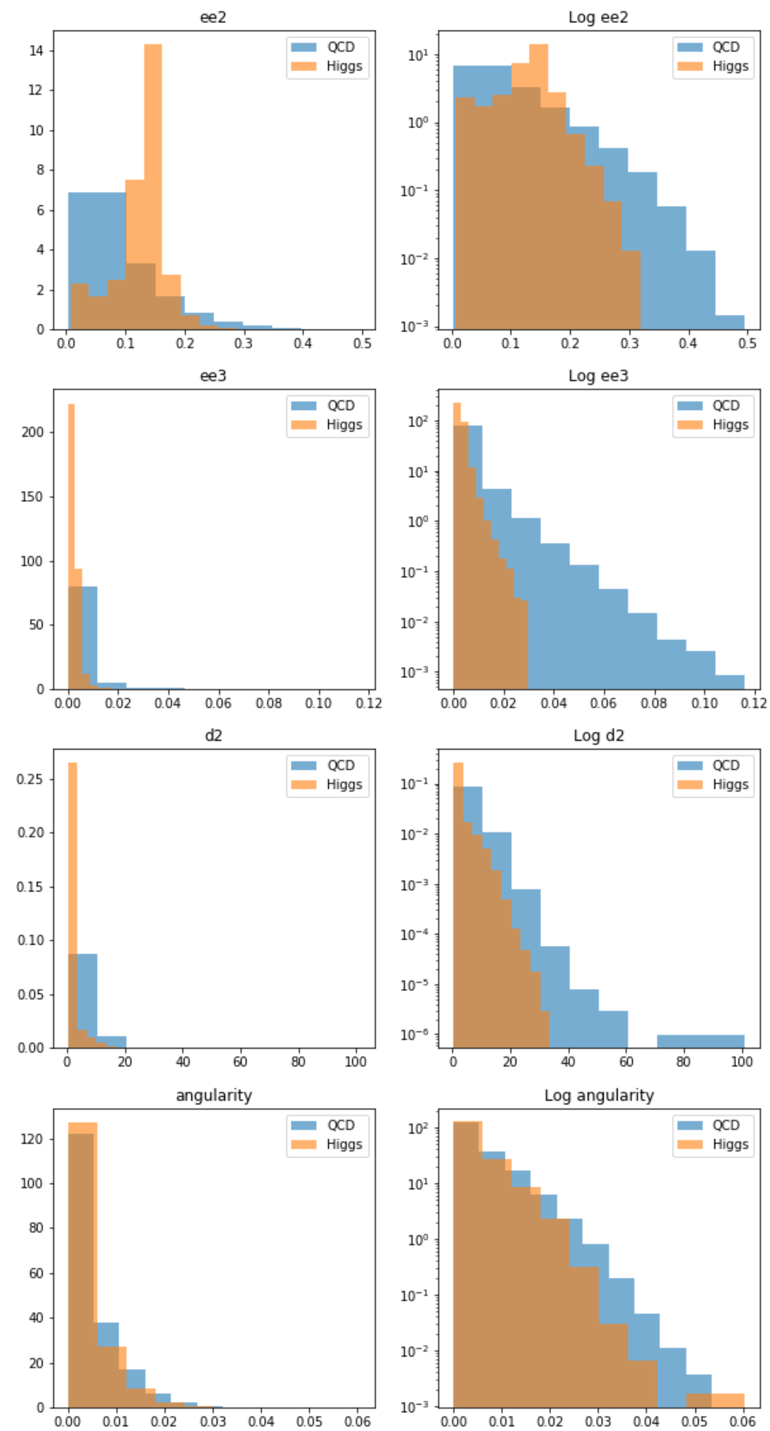

Figure 5. Histograms of ee2, ee3, d2, angularity data

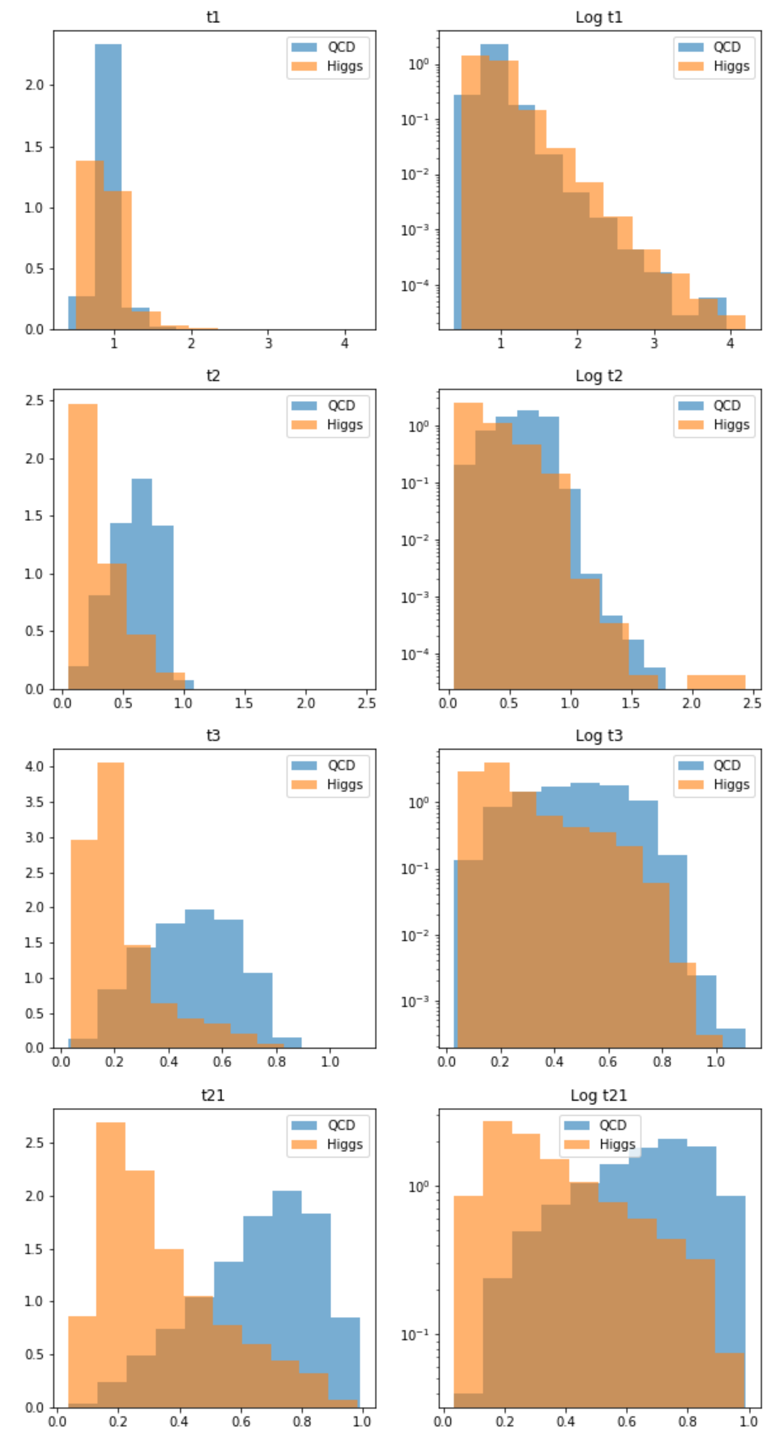

Figure 6. Histograms of t1, t2, t3, t21 data

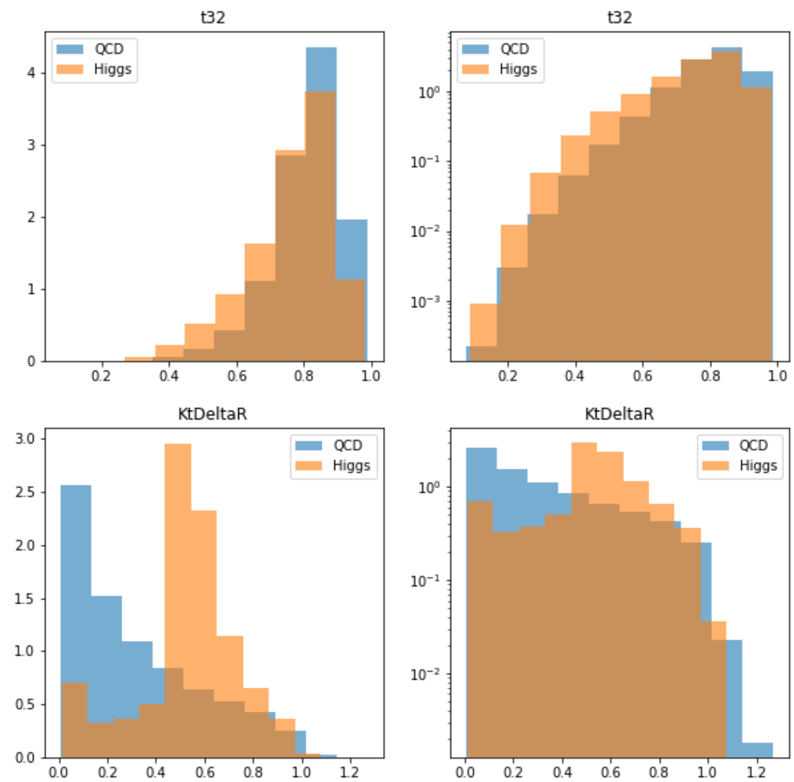

Figure 7. Histograms of t32,KtDeltaR data