

Measurement of the Higgs Boson Transverse Momentum in the Di-photon Channel with the ATLAS detector in Run 1

Robert Graham Reed

School of Physics, University of the Witwatersrand , Johannesburg 2050, South Africa

E-mail: robert.reed@cern.ch

Abstract. The Standard Model (SM) of particle physics, with the discovery of the Higgs boson, is a model of the known fundamental particles and their interactions. The data taken in the 2012 run was then compared to the Monte Carlo and an excess has been found in the Higgs transverse momentum in the di-photon and ZZ decay channels. A possible explanation is a beyond the SM scalar boson is being produced which would then decay into a dark matter particle and a Higgs boson that looks like the current SM. This dark matter particle would provide the Higgs with excess momentum which may account for the discrepancy observed. A first attempt at modelling the production of the heavier than the SM Higgs (or scalar boson) showed that as the centre of mass energies increase the production cross-section of the scalar boson increased faster than the SM Higgs boson. This indicates that if the hypothesis is true then we should expect greater Higgs boson productions during the 2015 run at higher centre of mass energies. A better understanding of the observed excess is needed before any further conclusions can be made.

1. Introduction

On July 4th 2012 both the ATLAS and CMS Collaborations announced the discovery of a Higgs-like boson with a mass of 125 GeV [2,3]. Over a year later in subsequent papers [4, 5] this boson was observed to be the Standard Model (SM) Higgs Boson with a significance greater than 7σ as seen in Fig. 1. The Higgs boson is predicted by the Standard Model as a consequence to spontaneous symmetry breaking which gives mass to elementary particles. The discovery has been a highlight for the LHC. The new particle is a tantalizing new tool for beyond the standard model searches.

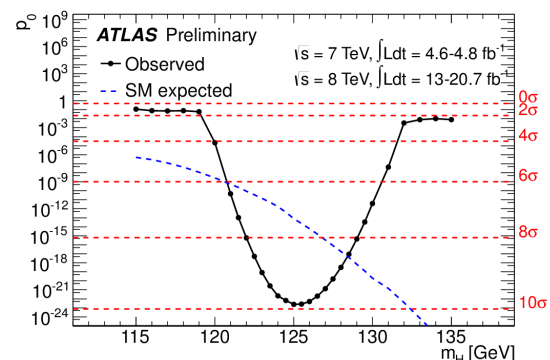


Figure 1: Combined search showing the local probability [1].

2. The ATLAS Detector

The ATLAS detector is one of two main general purpose detector at the LHC. The ATLAS detector is different in many respects to the CMS detector most noticeable is the air-core superconducting magnets that produce the toroidal field for the muon spectrometer. The detector is cylindrical in shape and has a forward-backward symmetry. The detector consists of concentric sub detectors. Starting from the inside we have the inner tracker and silicon microstrip detector located inside the transition radiation tracker which provide tracking in the pseudorapidity range $|\eta| < 2.5$, electromagnetic calorimeter and lead liquid-argon sampling device is divided into one barrel ($|\eta| < 1.475$) and two end cap regions ($1.375 < |\eta| < 3.2$), the hadron calorimeter is also divided into a barrel ($|\eta| < 0.8$) and extended barrel ($0.8 < |\eta| < 1.7$) both of which consist of steel and plastic scintillators. Each sub detector is designed to identify different particles, their energies and trajectories. After combining all sub detector readings and apply statistical techniques to extract the signals one can piece together a snippet of what occurred during a collision event.

3. Event Selections

An additional challenge is faced once the raw data has been reduced to "interesting" events. How we identify objects is a complicated process that involves many different techniques and statistical tools. In this proceedings I will not discuss in detail the object identification process but rather the event selection for the Higgs to di-photons channel only. The details of the object identification for the Higgs to di-photon channel can be found in Ref. [6].

To distinguish between electrons and photons the reconstruction algorithm looks for possible matches between energy clusters and tracks reconstructed in the inner detector and extrapolated to the calorimeter. Well-reconstructed tracks matched to clusters are classified as electron candidates while clusters without matching tracks are classified as unconverted photon candidates. These photon candidates are then calibrated using statistical tools that have been optimised for this task. When selecting photons its required to have two photons in the difucial region defined by $|\eta| < 2.37$ and must exclude the gap region defined by $1.37 < |\eta| < 1.56$. The two photons with the highest energy are then considered. The ratio of the transverse energy (E_T) to the invariant mass of the two photons ($m_{\gamma\gamma}$) for the leading and subleading photons must be greater than 0.35 and 0.25 respectively.

The measurement of the correct production vertex is important to accurately measure the invariant mass of the diphoton system. The vertex is selected from the reconstructed collision vertices using a neural-network algorithm. The efficiency of finding the correct vertex in simulated Higgs to diphotons is approximately 83 % which improves as the transverse momentum increases.

4. Higgs Kinematic Results

The higgs boson transverse momentum is studied as it is linked to the kinematics of the Higgs boson production. In this section I will show results of the Higgs boson transverse momentum in the diphoton channel for both ATLAS and CMS as well as the four lepton channel from ATLAS. Figure 2 shows the results of the Higgs boson transverse momentum in the diphoton decay channel at the ATLAS detector. The log scale on the y-axis must be noted. In this plot we have greater resolution in bin number due to the larger signal yield compared to the four lepton channel. We see a similar structure as before with low p_T being over shot by the MC, the region $20 < p_T < 100 GeV$ is undershot by the MC and high p_T is agreeable with predictions. Due to the higher signal yield the excess is more prevalent in the Higgs to di-photons channel. Figure 3a) shows the transverse momentum of the Higgs boson in a decay to four leptons at the ATLAS detector.

The first thing we notice is the large error bars on the data. Assuming these error bars reduce with more data we can see a structure in the p_T that is not predicted by the Monte Carlo (MC). The data is overshoot for low p_T , undershot for range of approximately $20 < p_T < 60 \text{ GeV}$ and matching fine for high p_T . Figure 3b) is the same result but from the CMS detector. Similar results are seen with an excess in the same region as before. Each plot shows an excess in the mid p_T range. How significant is this excess is the next natural question to ask. As a preliminary run a Kolmogorov-Smirnov test is performed on each individual plot and an overall KS test statistic is calculated.

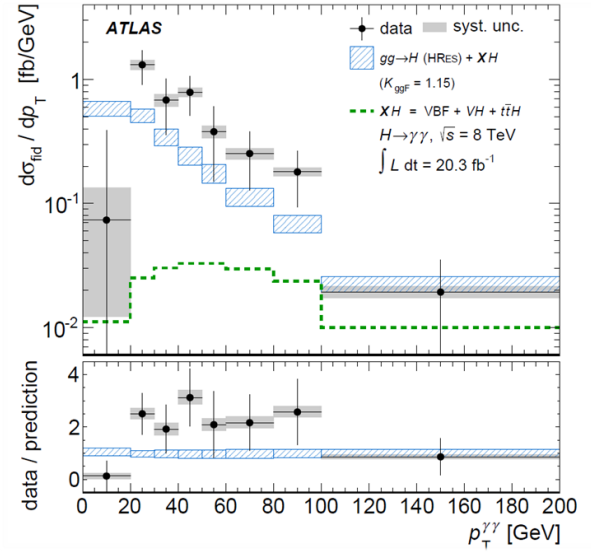
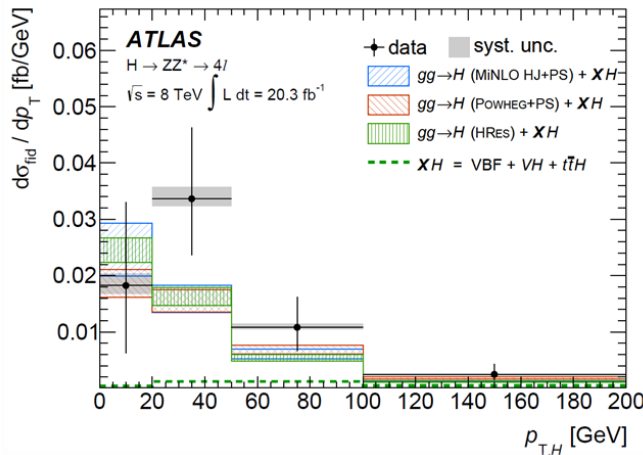
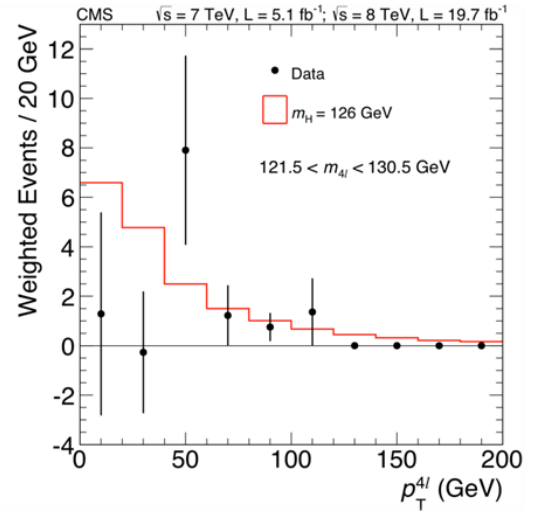


Figure 2: Transverse momentum of the Higgs boson in the diphoton channel.



(a)



(b)

Figure 3: Transverse momentum of the Higgs in the four lepton channel. a) ATLAS and b) CMS.

4.1. Kolmogorov Test

The two sample Kolmogorov-Smirnov test is used to test how likely two samples are produced from the same set. It is based on the maximum difference between an empirical and a hypothetical cumulative distribution. The test statistic is given by Eq. 1.

$$D_{n,n'} = \sup_x |F_{1,n}(x) - F_{2,n'}(x)| \quad (1)$$

Table 1: Kolmogorov-Smirnov Test Results

Channel	KS Value
$H \rightarrow 4l$ ATLAS	0.635814
$H \rightarrow 4l$ CMS	0.301351
$H \rightarrow \gamma\gamma$ ATLAS	0.029377
TOTAL	0.00563 $\approx 2.8\sigma$

where, $D_{n,n'}$ is the Kolmogorov-Smirnov test statistic KS , $\sup_x$ is the supremum or maximum of the set, $F_{1,n}(x)$ and $F_{2,n'}(x)$ are the empirical distribution functions. The distribution functions are calculated from the total number of events after taking into account the luminosity and differential cross sections for each graph independently. Table 1 shows the results obtained for each plot shown in Fig. 3 and Fig. 2. The most noticeable is the diphoton case which has a small test statistic. Taking the product of all three cases gives the overall test statistic which is equivalent to approximately 2.8σ .

5. Discussion and Conclusions

The results of the Kolmogorov-Smirnov test indicate a significant excess from two different decay channels which is seen in ATLAS and CMS. An excess of 3σ may or may not stay after the next data taking session in mid 2015. It is possible that this excess is merely a statistical fluctuation but a more exciting alternative is a beyond the SM explanation. The extra p_T could be explain by the production of an extra scalar boson that decays into a Higgs boson and dark matter. The Higgs boson recoils off the dark matter which can produce an excess in p_T that we observe.. Once the detector is online and new measurements are studied will we be able to better answer this question. The fact that there is currently an excess, even if it may be statistical fluctuations, warrants an investigation.

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