ZH Dark Photon Analysis with the ATLAS Experiment

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Introduction

The standard model (SM) provides a successful description of the fundamental particles which make up the visible matter in our universe and the fundamental forces governing their interactions. However, it is not the final theory as it fails to describe gravitational force and to answer the outstanding questions in particle physics such as the composition of dark matter. The experiments at the large Hadron Collider (LHC) aims to find a way to answer these questions.

The discovery of the Higgs boson by the general-purpose experiments, namely, ATLAS and CMS in 2012 revealed the agreement of the data with the predictions of the SM, furthermore, the mechanism by which fundamental particles acquire mass was explained. Multiple searches have studied the final states of the decayed Higgs boson. Dark Photon searches in ATLAS aims to look for $\boldsymbol{\gamma}_{\mathrm{D}}$ which is a massless dark photon coupling to the Higgs through a charged dark sector in ZH production mode, such invisible final states could be a sign of physics beyond the standard model (BSM). Where $\boldsymbol{\gamma}_{\mathrm{D}}$ acts as a mediating particle since particles in the dark sector don't interact directly with the SM particles.

The data used for the ZH dark photon analysis were collected by the ATLAS experiment, where the center of mass energy **equals** 13 TeV.

This paper aims to provide an overview of the LHC and ATLAS, followed by a discussion on the computing framework used in the analysis. Finally, the physics signal, background contributions and plotting are described.

The Large Hadron Collider (LHC)

The Large Hadron Collider (**LHC**) consists of a ring of superconducting magnets and radiofrequency cavities forming a circular accelerator which was designed to produce collisions of two proton beams at high energies [2]. The process starts with the acceleration of protons through a series of accelerators, followed by the injection in bunches of around 10^{11} protons into the LHC. The two proton beams are to circulate in opposite directions in separate beam pipes at a speed that approaches the speed of light before the collision. Finally, the presence of magnets results in the focusing of the two beams such that collisions can be detected at four interaction points by CMS, ATLAS, ALICE, and LHCb. Data is to be collected from as many collisions as possible as we are more interested in studying rare processes.

The ATLAS Detector

ATLAS stands for (**A T**oroidal **L**HC **A**pparatu**S**), it is a general-purpose experiment at the LHC. With a length of 44 meters and a weight of 7,000 tons, ATLAS is the largest particle detector located around one of the interaction points [3]. Its layered structure consists of three main parts, namely, the inner detector, calorimeters, and the muon spectrometer.

The inner detector provides tracks for any electrically charged particle, it is surrounded by calorimeters which measure the deposited energy by particles or showers. Two main calorimeter systems are present, the inner calorimeter which is known as the electromagnetic (EM) calorimeter is of fine granularity to absorb the energy deposited by photons and charged particles. While the outer one is referred to as the hadronic calorimeter, it is designed to reconstruct hadronic jets. The muon spectrometer tracks highly energetic muons that penetrate through the inner detector and calorimeters; thus, it is represented by the outermost layers of the detector in figure 1.

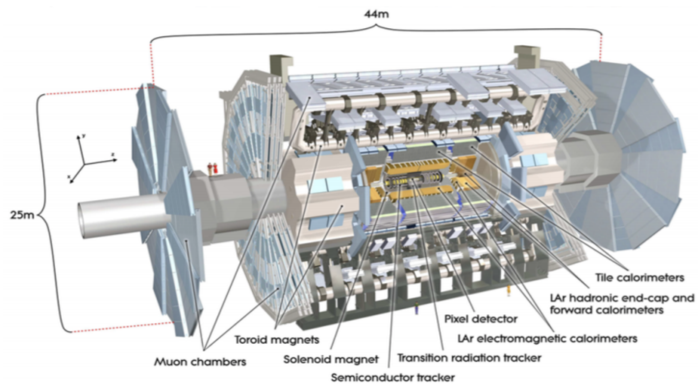

Figure.1: Schematic of The ATLAS Detector [3]

Computing Framework

A software that enables our code to focus on the physics analysis is referred to as the framework. The two main parts of the framework are the analysis and plotting. The frameworks used in the ZH dark photon analysis are the STAnalysisCode framework and the STPostProcessing framework. The STAnalysisCode framework produces flat trees called “mini-Ntuples” by applying skims and slims to the derived data analysis objects (DAOD) files [4]. The flat tree contains all quantities for each event in its branches and 1D histograms with the cut-flows applied to make the Mini-Ntuple. It is based on “SUSYTools" which are toolkits plugged into the code to obtain fully calibrated or corrected physics objects. Then, the STPostProcessing framework is used to create micro-Ntuples which are obtained from skimming/ slimming cuts applied to mini-Ntuples while they are on the GRID to reduce the size [4]. This is where cut-flows, histograms, and plots are created and the cuts for the signal regions and control regions and normalization are defined. The initial step is to set up the framework by going to the analysis directory, in our case, ZHdarkPhoton, then cloning the GitHub repository into the source directory to read the data from the samples online. This is followed by setting up the AthAnalysis with 21.2.160 release and compiling the code.

Physics Signal and Background Contributions

Monte-Carlo (MC) is used to model the physics signal and background yields by simulating events; two samples of simulated events are produced, namely, signal events and background events. In this analysis, the process of interest is the decay of the Higgs into an isolated photon and a massless dark photon $\boldsymbol{\gamma}_D$ that is not detected by the ATLAS detector in the ZH production mode as illustrated in figure2.

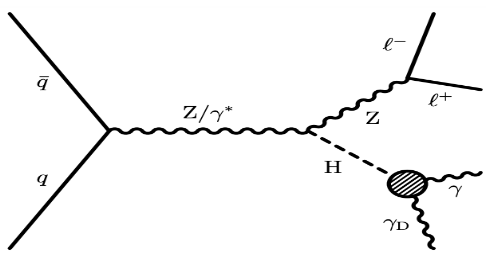

Figure2. Feynman diagram for the $H \rightarrow \gamma\boldsymbol{\gamma}_D$ final state produced through ZH [5]

The simulated signal event is of the following final states: two leptons from the Z decay, one photon, and missing transverse energy E_T^{miss} (corresponding to $\boldsymbol{\gamma}_D$). It is based on the standard model (SM) $H \rightarrow \gamma\gamma$ events produced via ZH where one photon is removed and its transverse momentum P_T is added to the E_T^{miss} calculations [5].

$$ZH \rightarrow \ell^+ \ \ell^- + \boldsymbol{\gamma} + E_T^{miss} \qquad (1)$$

Backgrounds arise from events with $\ell^+ \ \ell^- + \boldsymbol{\gamma} + E_T^{miss}$ which are mainly produced by the SM Higgs related processes alongside with reducible and irreducible backgrounds which are the two kinds of backgrounds in any analysis. Reducible backgrounds are produced by a particle faking the final state particles that we are looking for, for example, fake E_T^{miss} from jets (Zγ + jets) and fake E_T^{miss} and γ from jets (Z+ jets). While irreducible backgrounds are of the same final states of the signal event such as the ones from di-bosons (VV), which are of low contribution compared to the reducible backgrounds from fake E_T^{miss} and jets giving fake photons.

Plotting

The produced background,event, and data micro-Ntuples are used in the blinded signal region to look at some variables and to produce cut-flows and histograms located in root files. Thus, we define the main macrons used, namely, plotEvent.py, CutsDef.py, and Input.py. CutsDef.py macro is used to apply cuts to signal region and background regions depending on the shape of the MC signal and background distributions in different variables. It contains a list of pairs of cutnames and selection keys. Additionally, Input.py macro handles MC samples where each background and signal sample has an ID and reads in the micro-Ntuples, creating a python map from sample keys to run numbers. In order to obtain the final plots, the X and Y axes are defined using drawStack.py followed by obtaining the output data (data1516) and the simulated MC samples (MC16a). Data/Mc distributions in the blinded signal region (uu-channel) are produced by running the macro via python over the output. See figure 3.

The signal and backgrounds are normalized to 36 fb^{-1} and the histograms for different mass points are shown. The variables are chosen to discriminate between the backgrounds and signal, the figure below shows only three discriminating variables.

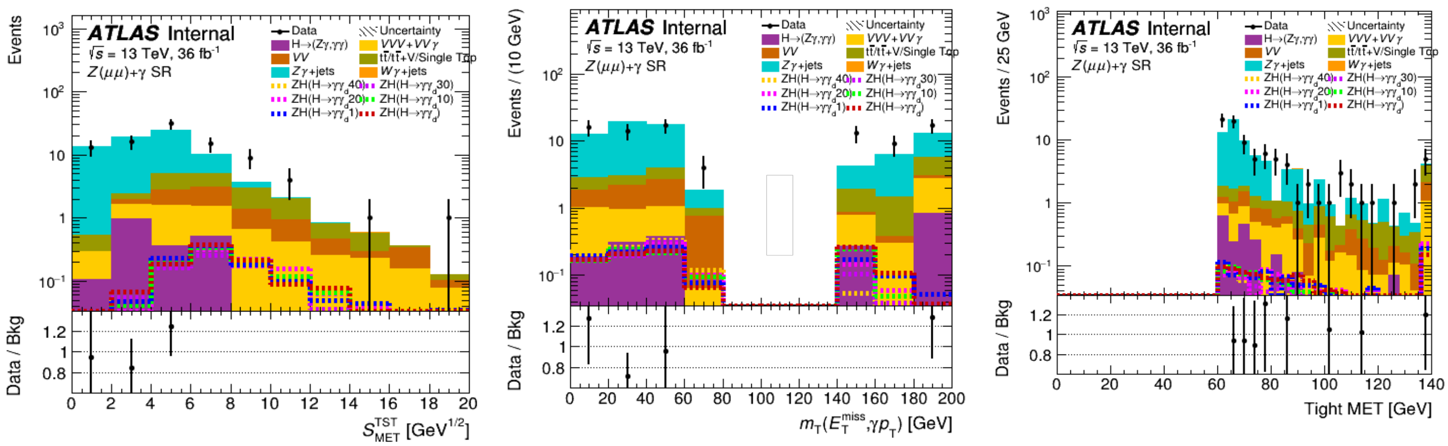

Figure3. Data/MC distribution in Blinded SR (uu channel)

Conclusion

The analysis framework used for the ZH dark photon searches in ATLAS enables the production of micro-Ntuples, plots, and cut-flows. In spite of the importance of the massless dark photon in understanding the dark sector, the $H\gamma\boldsymbol{\gamma}_D$ analysis is challenging due to the large amount of estimated background. Further studies of backgrounds such as ttbar and VV are required for the analysis.

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