Studying the effects of pileup on the leptonic properties in the $H \rightarrow$ ZZ $\rightarrow 4\ell$ channel using the ATLAS detector

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Abstract. The background composition and shapes are studied in spectral control regions which are constructed by inverting selections or lepton identification requirements. Here we show the effect of pileup for the $H \rightarrow$ ZZ $\rightarrow 4\ell$ channel with weighted histograms, normalized to the expected luminosity. The background considered is the $qq \rightarrow ZZ$ irreducible background which is from a dominant quark-antiquark initial state. We present on the event yields between mc16a and mc16d samples and the overall difference is approximately 3.77%. Comparisons between the two samples on the effect of pileup are also presented which show no effect of pileup between 2015 to 2017 data.

1. Introduction

Since the discovery of the Higgs boson at a mass of 125 GeV at the Large Hadron Collider (LHC) at CERN, one important question is whether the newly discovered particle is part of an extended scalar sector as postulated by various extensions to the Standard Model (SM) [1]. These extensions predict additional Higgs-like bosons, motivating searches in an extended range of mass. This paper reports on searches for a heavy resonance decaying to a pair of Z bosons encompassing a final state of charged leptons (electrons or muons), $ZZ \rightarrow \ell^+\ell^-\ell^+\ell^-$ as shown in Figure 1. Events with four muons (four electrons) associated to the two Z bosons are called 4μ ($4e$) events. In cases where the leading Z boson is formed from muons (electrons) and the subleading from electrons (muons) then the events are labelled as $2\mu 2e$ ($2e2\mu$).

We study the effect of pileup for the $H \rightarrow ZZ \rightarrow 4l$ channel for both 2015 + 2016 (mc16a) and 2017 (mc16d) datasets. Furthermore, the pile-up profile is reweighed to a luminosity weighted combination of the pileup conditions for the two years. This analysis focuses on the intermediate mass ranges (100 - 800) GeV for the heavy scalar

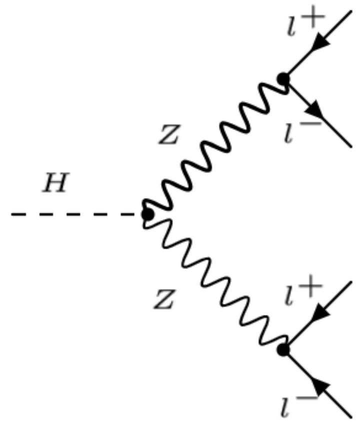


Figure 1: Illustration of the $H \rightarrow$ ZZ $\rightarrow 4\ell$ channel.

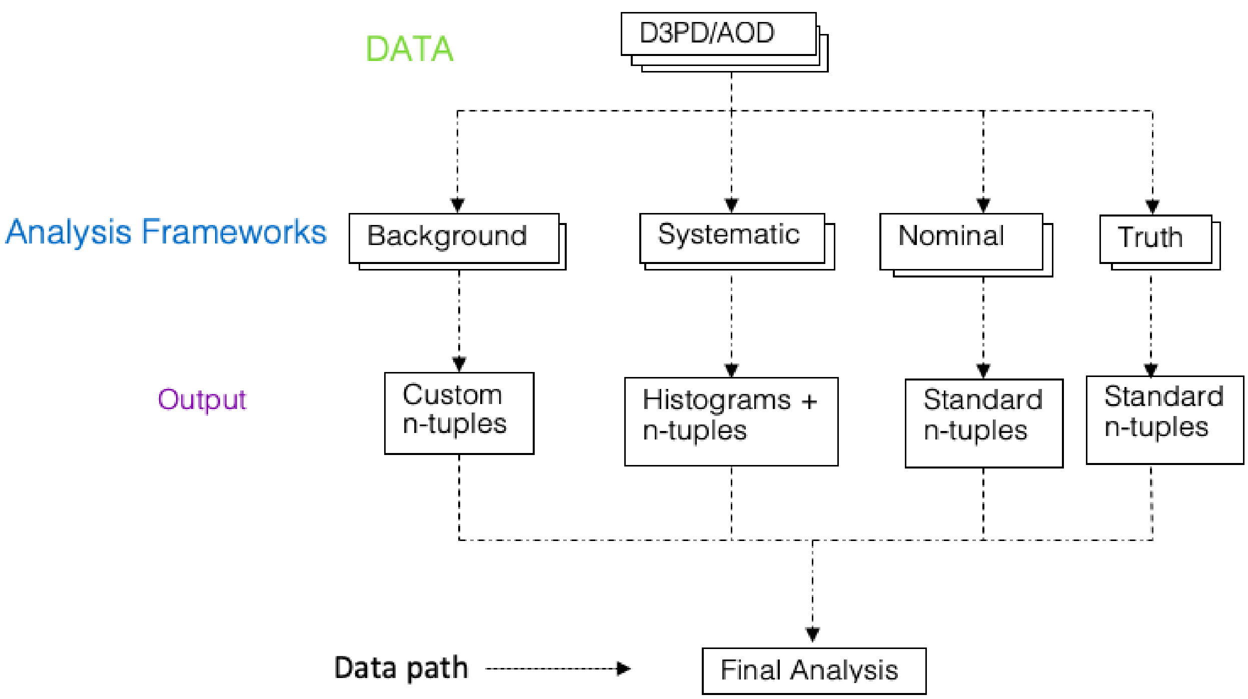


Figure 2: Designed $H4\ell$ Run2 analysis framework model.

boson and the events generated are fully simulated using the ATLAS detector simulation within the $H4\ell$ framework (detailed in the next section) as displayed in Figure 2. Monte Carlo (MC) simulation is used to model the detector response for the background process. The main background contribution to this decay channel comes from the ZZ irreducible background, which is from a dominant quark-antiquark initial state and

Event Pre-selection
Veto
Veto any event where detector is not working properly
Triggers
Single electron, single muon, di-electron, di-muon and electron-muon triggers
Electrons
Caliberated Loose Like quality electrons with $E_T > 7$ GeV and $\|\eta\| < 2.47$
Muons
Smeared combined or segment-tagged muons with $p_T > 6$ GeV and $\|\eta\| < 2.7$,
Maximum one calo-tagged or standalone muon in the quadruplet,
Smeared calo-tagged muons with $p_T > 15$ GeV and $\|\eta\| < 0.1$,
Smeared stand-alone muons with $p_T > 6$ GeV, 2.5< $\|\eta\| < 2.7$ and $\Delta R > 0.2$ from closest segment-tagged
Jets
Calibrated R= 0.4 Anti kT jets with $p_T > 25$ GeV and $\|\eta\| < 2.4$ or $p_T > 30$ and 2.4< $\|\eta\| < 4.5$
Overlap removal
Remove overlap between different physics objects

Table 1: Summary of the nominal $H4\ell$ event selection requirements.

was modelled using Sherpa 2.2.2 event generator [1]. Other important background contributions come from $t\bar{t}$ and Z+jets which contribute to the reducible background. These are usually caused by fake leptons from jets, top quark and bottom quark. Additionally, carefully selected impact parameter cuts and isolation cuts on the events will suppress this background contribution [2].

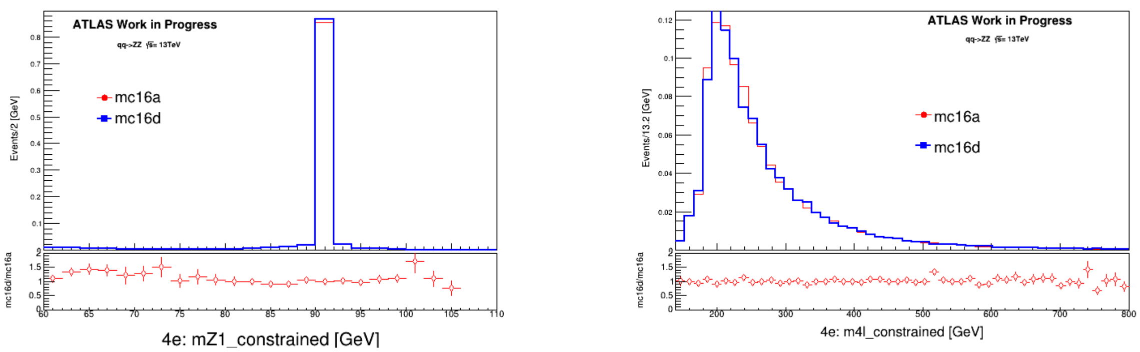
2. $H4\ell$ Framework

The analysis framework is important as it used to reduce AODs/D3PDs/xAODs to a manageable size and format that we use for producing final results and plots. This is accomplished by imposing specific analysis cuts and vetoing events that do not pass the full selection requirements. Table 1 summarizes the cuts used by the $H4\ell$ group for its nominal analysis. These cuts match the kinematic distributions from the HZZ decay channel and also reduce background events, where the jets may have been misidentified as leptons [3]. To estimate the backgrounds, control regions are created by inverting and relaxing isolation requirements on electrons or selecting the quadruplets with different flavor composition and charges [1].

Electron clusters are reconstructed using a sliding window algorithm, which searches for small-radius energy deposits contained in the Electromagnetic (EM) calorimeter. Furthermore, to improve reconstruction for electrons (which undergo energy loss due to bremsstrahlung) the track associated with a cluster which passes the loose shower shape requirement, is refitted using a Gaussian-Sum Filter [3]. Additionally, muon track reconstruction is first performed independently in the Inner Detector (ID) and the Muon Spectrometer (MS). Hit information from the individual subdetectors is then used in a combined muon reconstruction, which includes information from the calorimeters.

Samples	4μ	$4e$	$2\mu 2e$	Overall
mc16a	249.92	157.76	398.38	805.76
mc16d	240.28	152.44	383.77	776.49
mc16a/mc16d	1.04	1.03	1.03	1.03
Rel. diff in %	4.01	3.52	3.81	3.77

Table 2: Summary of the yield calculations for 2015-2017 in the four decay channels after the event selection, in the mass range 140 GeV < m_{4l} < 130 GeV.



(a) (b)

Figure 3: Shape comparisons between mc16a and mc16d for mZ_1 and m_{4l} for only the $4e$ final state.

Once the events have been selected, variables important to the final analysis are calculated and stored in minitrees. For the MC events, weight variables for which the overall normalization and truth matched information is considered, are calculated and saved in the final output.

3. Results

3.1. Yield Events

A summary of the yield events is shown in Table 2 in the $ZZ \to 4\ell$ channel in the region 140$\leq m_{4l} \leq$800 GeV. The event yields are computed after the aforementioned standard selection criteria are applied, which corresponds to a total integrated luminosity of up to 50.0 fb^{-1} for the 2015 - 2017 datasets [1]. They are calculated per decay channel (4μ, $4e$ and $2\mu 2e$) and for all the channels combined. The background yields are either obtained from MC for the ZZ continuum, or using data driven techniques for the reducible contributions, as described previously. However, in the high mass region, we select $2e2\mu$ or $2\mu 2e$ by taking the pair closest to the Z- mass ($\approx$ 91 GeV). Additionally, with both pairs on-shell, it is only the measurement resolution that tends to decide which

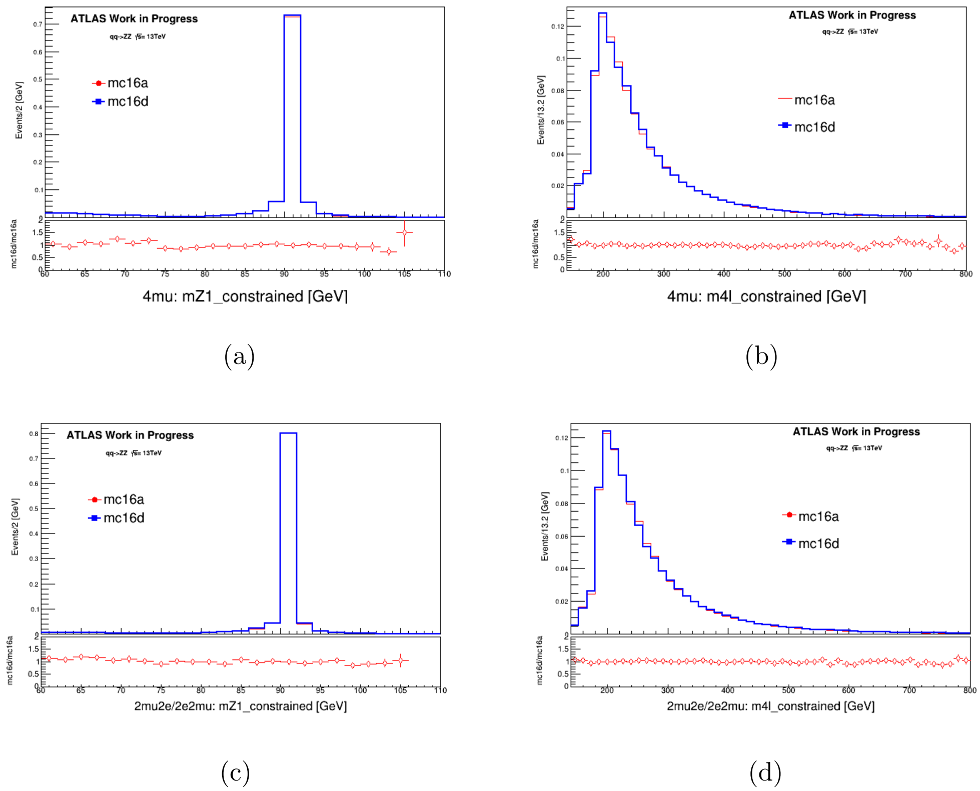


Figure 4: Shape comparisons between mc16a and mc16d for mZ_1 and m$_{4l}$ for the 4μ and 2μ2e final states.

way the pairing goes. As expected, the 4μ final state has the highest efficiency and the $4e$ final state has the lowest efficiency since muon kinematic cuts are looser for electrons.

We then compared the MC data between 2015 to 2017. Figure 3 shows shape comparisons for only the 4e final state for mZ_1 and m$_{4l}$ distribution for the $qqZZ$ background in the 60< mZ_1 <110 GeV region [3]. Leptons are paired to leading and subleading Z bosons, the leading pair (mZ_1) is taken as the Z-pair closest to Z mass and the pair that is next-to-closest to the Z mass in the range 12 < m$_{ll}$ < 115 GeV is taken as the subleading Z-pair. The invariant mass of the four leptons is known as m$_{4l}$ [3]. We also show shape comparisons for 4μ and $2\mu 2e$ final states in Figure 4. No significant differences between the two MC samples can be observed for all the final states.

4. Conclusion

Our results for the yield events were as expected, with 4μ final state having the highest efficiency. The event yields are higher for mc16a than mc16d, however the overall difference was 3.77%.

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For the shape comparisons, between mc16a and mc16d, their ratio was found around 1 and only a few statistical fluctuations were observed. Therefore, no significant effect of pileup was observed on the mass resolution, energy/momentum scale.

References

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[3] Aaboud M *et al.* (ATLAS) 2018 *Phys. Lett.* **B784** 345–366 (*Preprint* 1806.00242)