Estimation of fake rate background in same sign $W^{\pm}W^{\pm}$ production at the LHC with ATLAS Detector

X. Thusini, Dr A. Hamilton, Dr S. Yacoob

Department of Physics, University of Cape Town, South Africa

E-mail: `xolisile.octavia.thusini@cern.ch`

Abstract. At the Large Hadron Collider, $W^{\pm}W^{\pm}$ boson scattering has been identified as a promising interaction for understanding of the Electroweak Symmetry Breaking. This is a rare Standard Model process with small cross-section. The previous measurements have found evidence for the process to a significance of 4.5 σ using $\sqrt{s} = 8$ TeV proton-proton collision data recorded by the ATLAS detector. This paper aims at understanding the fake background in same sign $\ell^{\pm}\ell^{\pm} + E_T^{miss} + jj$ channel coming from the scattering of two W bosons with the same electric charge. The two W's are required to decay leptonically with only electrons and muons in the final state. The background processes that can mimic the signature of same sign $\ell^{\pm}\ell^{\pm} + E_T^{miss} + jj$ are W+jet, $t\bar{t}$, single top or QCD multijet processes where one or two jets are mis-reconstructed as leptons. The main objective of this work is to understand non-prompt, fake, backgrounds coming from $t\bar{t}$ decay using Monte Carlo simulations.

1. Theoretical Background

The study of fundamental particles began in the first decade of 21st century when scientists started to observe new particles as a result of an increase in collision energies. The properties of these particles were not well explained till late 1970's when physicists of the time developed what became the Standard Model (SM) [1, 2, 3, 4, 5, 6] of particle physics. This is the only model that successfully describes the properties and interactions of the fundamental building blocks of nature at the smallest scales. The W boson is one of the SM particles responsible for weak interactions. It was discovered in 1983 at LEP collider [7, 8]. The W boson can be positively or negatively charged and has a mass of 80.385 ± 0.015 GeV.

In proton-proton collisions, same sign WW boson scattering can occur through non-resonance direct processes depicted in Figure 1 where both W bosons decay leptonically into $e\nu$ or$\mu\nu$. This is a rare Standard Model process with small cross-section that has not yet been observed, but previous measurements have found evidence for the process to a significance of 4.5 σ by ATLAS experiment [9] and 2.0 σ by CMS experiment [10]. The experimental signature of two same-signed leptons (electrons or muons), missing transverse energy, and two jets is used because of the relatively low background from diboson production, $t\bar{t}$ and $Z + jets$.

$$W^{\pm}W^{\pm} \rightarrow \ell^{\pm}\ell^{\pm} + E_T^{miss} + jj$$

This paper presents some of the ongoing work in understanding the backgrounds in the search for same sign WW boson scattering (ssWW) within the ATLAS experiment.

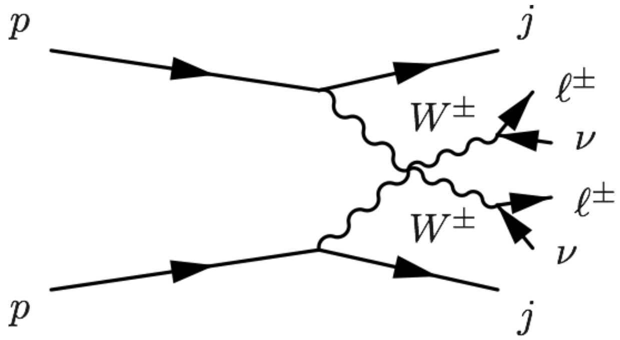

Figure 1. 1st order Feynman diagram of the same sign WW boson scattering.

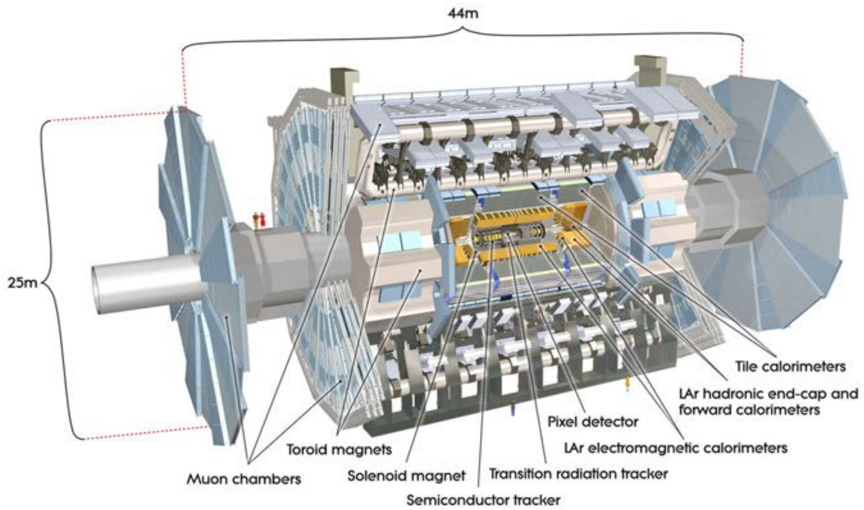

Figure 2. ATLAS detector and its subsystems[11].

2. The LHC and the ATLAS Experiment

In 2001, the LEP collider at the CERN was decommissioned so that the Large Hadron Collider (LHC) [12] could be installed in the 27km tunnel. The primary goal of ATLAS was to observe the SM Higgs particle. Inside the LHC tunnel, two beams of protons circulate in opposite directions and collide at four points instrumented with detectors. In the middle of 2015, the LHC started running in proton-proton collision mode at a centre of mass energy of 13 TeV and luminosity of about 1x10^{34} cm^{-2}s^{-1}. To date, the LHC has delivered approximately 8 fb^{-1} of data under these conditions.

ATLAS detector [11] is one of the general purpose experiments installed on the LHC. It is made up of cylindrical barrel region and end-cap region on either side, refer to Figure 2. Both barrel and end-cap are comprised of many subsystems that are classified into three sub-detectors; inner tracker, calorimeters and muon spectrometer. Each subsystem is designed to measure specific properties of the particles passing through it to identify the signature they leave in the detector. A particle is identified either by interacting directly with the detector or by its decay into particles which can be then interact directly. It is possible for the detector to misidentify a particle. These fake signatures contribute to the background in the search for ssWW. To better model the backgrounds, particle physicists rely on Monte Carlo numerical methods.

3. Event Generators and Detector Simulations

In particle physics experiments, Monte Carlo (MC) based event generators and detector simulations are critical for understanding the data produced. The event generators model the proton-proton collisions, while the detector simulations model the interaction of particles in the detector. The MC samples thus come with two pieces of information; the *truth* information including the list of particles produced in the event generator and the *reconstructed (reco)* information containing the signatures that were reconstructed with a detector simulation framework based on GEANT4 [13]. By comparing the *reco* to the *truth*, the MC samples can be used to estimate the amount of mis-modelling in the reconstruction of particle signatures.

To compare the *reco* to *truth*, each reconstructed object is required to have a corresponding truth object within a specified distance in $\eta - \phi$ space: $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$. ϕ is the azimuthal angle, $\phi = \arctan\frac{y}{x}$, measured in the $xy-$plane. At hadron colliders, scientists deal with very energetic products of the collision, in this highly relativistic regime changes in rapidity Δy are Lorenz invariant. Hence, the rapidity (y) which reduces to the pseudo-rapidity (η) when the particle mass can be neglected, is used as a co-ordinate in the $yz-$plane. Both these parameters are computed as follows: $y = \frac{1}{2}\ln\frac{E+p_z}{E-p_z}$, where E and p_z define the energy and momentum of the particle along the $z-$axis, respectively, and $\eta = -\ln\left(\frac{\theta}{2}\right)$.

The ATLAS standard comparison algorithm, called the 'ATLAS MC Classification Tool' was developed by the ATLAS analysis software group in order to classify reconstructed objects such as electrons, muons, taus and photons according to their truth origin or ancestry. However, this classification tool has some limitations, it failed to classify nuclei, some hadrons and neutrinos for a significant fraction of the semi-leptonic $t\bar{t}$ events that pass the ssWW event selection criteria. Classification of these fake events is important for understanding the non-prompt background, coming from a decay of hadrons and not from a W boson. For these cases where the ATLAS tool failed to do the classification, a new tool called 'My MC Truth Classification Tool' has been developed.

The flow chart depicted in Figure 3 shows how both of these tools work. The ATLAS MC Classification Tool takes *reco* lepton and checks whether it has a truth particle associated with it. For the cases where this fails, My MC Truth Classification Tool takes the same lepton and return the list of all the closest *truth* particles within the cone size of $\Delta R = 0.2$. At the next stage it picks the particle with minimum ΔR from the list and checks if it belongs to the same decay chain as the other particles in the list, if it does the first generation is used as *origin*. The *type* depends on whether the list contain hadrons.

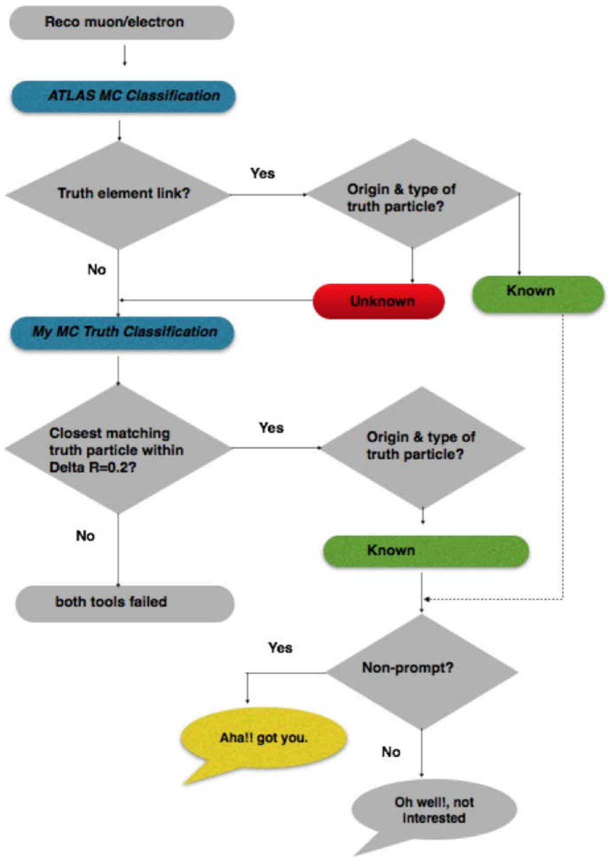

Figure 3. Flow of information between two classification tools.

4. My Truth MC Classification tool

Understanding the format of the event generator record is an important first step in classifying the truth origin of reconstructed signature as this may differ depending on the type of the generator. The decay chain from semi-leptonic $t\bar{t}$ event simulated by Sherpa event generator [14] is given in Figure 4. When there is hadronisation involved along the decay channel, it is more likely to reconstruct a lepton from hadron decay as a 'real' lepton, in this scenario a μ^-. This particular event illustrated in the diagram has two *reco* leptons, the first one is associated with *truth* e^- the second one has a μ^- as the closest *truth* match.

In addition to the non prompt background due to hadronisation, there are other classes of events that the ATLAS official tool classifies as two isolated leptons with opposite sign. When looking at the details of the truth record, the reason they pass the ssWW selection is that there is a photon conversion that is not property recorded by the tool.

5. Results and Discussion

Leptons originating from the underlying event are referred to as Background (Bkg) leptons. Mesons and baryons are hadrons, any lepton coming from these particles is non-isolated. The classification of truth particles for ATLAS standard tool is shown in Figure 5. However, other events failed the tool, indicated with red, this are the inputs in My MC Truth Classification tool, the distribution of truth origin as an output of this tool is shown in Figure 6.

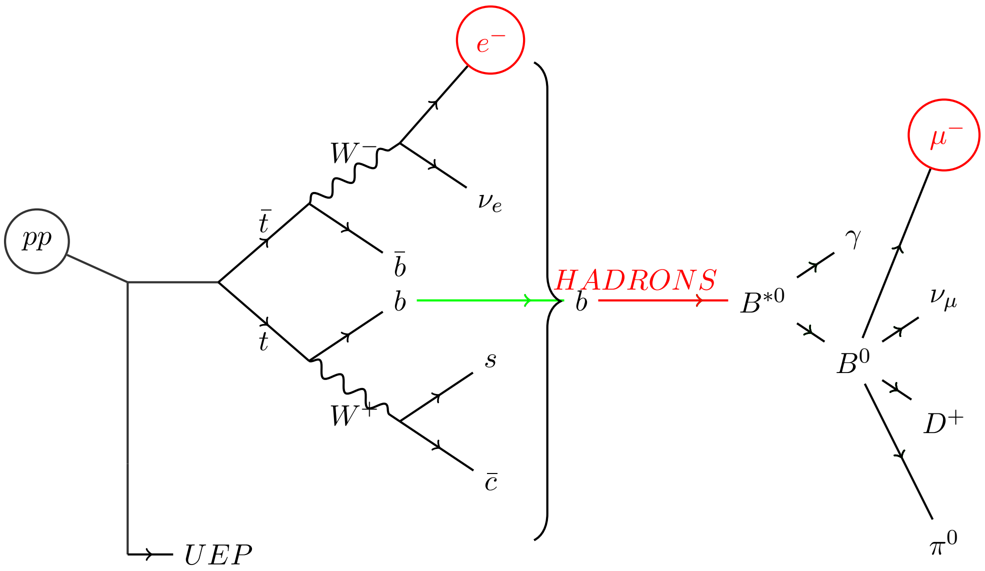

Figure 4. This diagram shows how $t\bar{t}$ event can end up being reconstructed with two same sign final state leptons, circled in red. One of these leptons, the μ^-, is a fake, or in this case non-prompt lepton; meaning that it come from a hadron and not from a W boson. *UEP* stands for underlying event particles and *pp* means proton-proton collision.

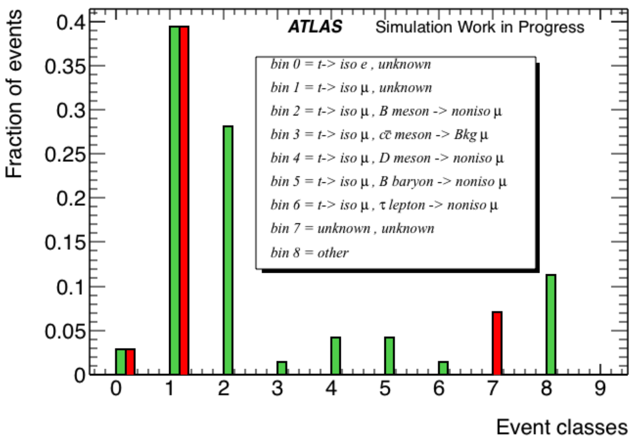

Figure 5. Different cases where $t\bar{t}$ events fake signal events with two leptons, electrons or muons, as defined by **ATLAS MC classification tool**. Each event is required to have two leptons, the plot shows the truth origin and type for both leptons. The unknowns are indicated in red, and are classified in My Truth MC Classification tool.

6. Conclusion

A new MC classifier tool has been developed to classify the truth origin of reconstructed signatures and to understand non-prompt background in $t\bar{t}$ production process. Preliminary results are summarised in figure 6 where we see that almost 40% of events which pass our selection are from an unknown source according to the standard ATLAS tool, and 27% from B meson decays. The events from unknown sources in figure 6 are further investigated using a cone matching algorithm and the results of this, summarised in figure 7, show that the dominant

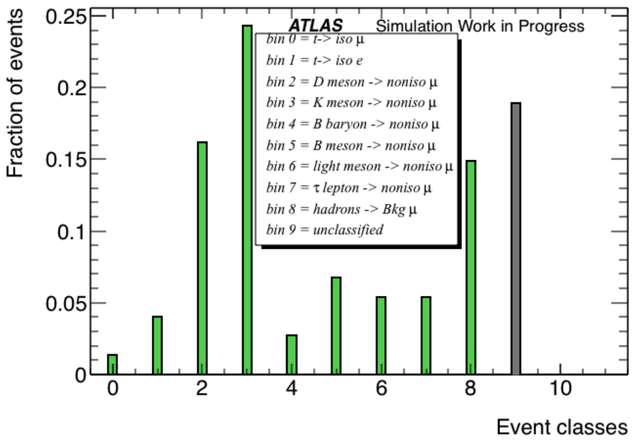

Figure 6. Truth origin and type of reconstructed leptons that failed ATLAS standard tool. These are the results from **My MC Truth Classification tool**. The case where both tools failed is marked in grey.

contribution is from D mesons. However 20% of these events remain unclassifiable. As future work, an understanding of this type of background will be used to optimise isolation and signal-to-background ratio for fake background studies in same sign WW production.

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