Introductory look at Z boson production at 5TeV

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Abstract

The presented report contains an introductory analysis of Z decay with ATLAS data at 5TeV through the use of the ROOT environment. The event selection is performed with a ROOT program and electron and muon channels are analyzed. The comparison of our data samples with Monte Carlo simulation leads us to the application of a reweighting and the proposition of further corrections. The Monte Carlo reweighting was motivated by the discrepancies encountered for different distribution. We observe better simulation data agreement in the number of vertex distribution after this procedure. To further improve the simulation the application of additional energy scale corrections is suggested.

Summary

1 Introduction

The ATLAS experiment

The ATLAS experiment is one of the four major experiments at the Large Hadron Collider (LHC) at CERN located in Geneva. ATLAS (A Toroidal LHC ApparatuS) is one of the seven particle detectors (ALICE, ATLAS, CMS, TOTEM, LHCb, LHCf and MoEDAL) that the Large Hadron Collider encompasses and one of the two general purpose detectors, with CMS. It has been designed to take advantage of the high energy available at the LHC and observe phenomena that involve massive particles we were not able to observe using earlier accelerators with lower energy.

The ATLAS Detector

ATLAS is a cylindrical detector 46 metres long and 25 metres in diameter, and weighs about 7,000 tonnes, including more than 3000 km of cable. Its geometry allows for an almost full solid angle coverage around the point of interaction. The inner detector consists of layers of silicon pixel and microstrip detectors and a straw-tube TRT (transition radiation tracker). It covers a pseudorapidity of $|\eta| < 2.5$. This inner detector reconstructs charged tracks and vertexes. The magnetic field of $2T$ is created by a superconducting solenoid.

The solenoid is surrounded by calorimeters, a high granularity lead/liquid-argon electromagnetic calorimeter and an iron/scincillating-tile hadronic one. This allows the reconstructions of jets, electrons and photons. The reconstruction of muons takes place in the outermost layers of the detector via the muon spectrometer which has high precision tracking chambers. In the figure it is possible to appreciate the detector and its subsystems:

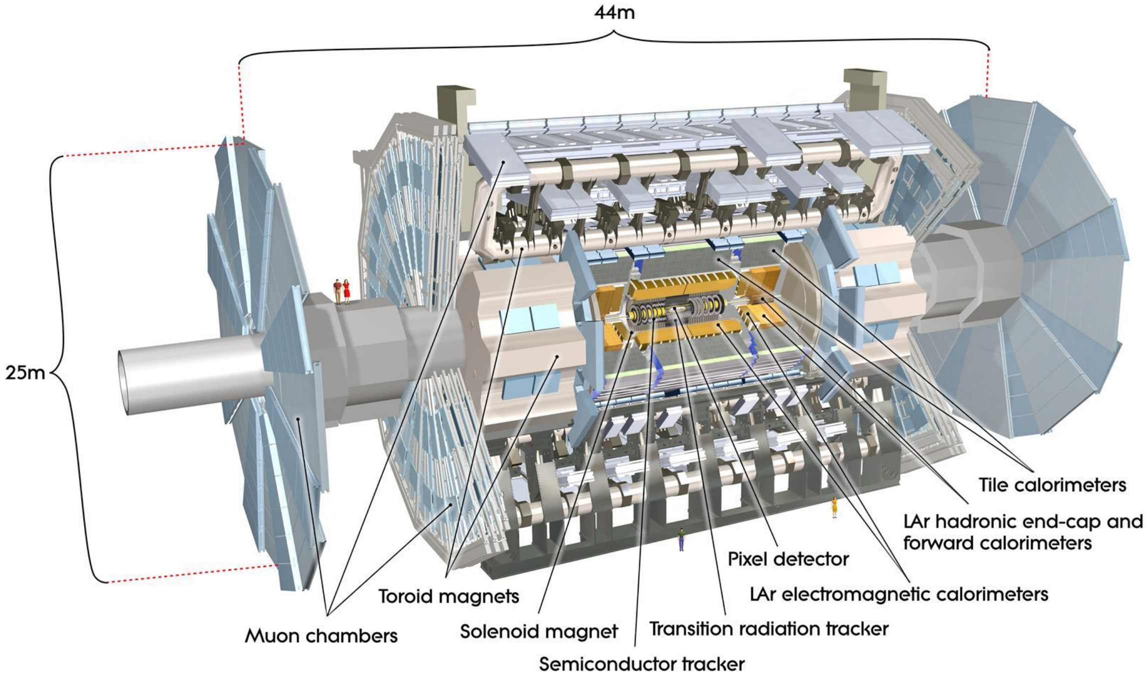

Figure 1: The ATLAS detector and its subsystems

W/Z bosons decay study importance

The W and Z bosons have been the subject of detailed measurements at both electron-positron and hadron colliders since their discovery in the 1980s. The ALEPH, DELPHI, L3 and OPAL experiments at the large electron–positron collider (LEP) preformed many precision studies of these vector bosons. At hadron colliders, single vector boson production has been explored at 0.63TeV CERN $Sp\bar{p}S$, at 1.8TeV and 1.96TeV at the Tevatron and at 2.76TeV and 5TeV at LHC. This report focuses on the latter 5TeV ATLAS data.

Hadron colliders offer a distinct advantage for the vector boson observation over electron-positron ones, since the number of single vector boson events is larger. However, because of the uncertainties in the proton structure, the parton center of mass cannot be determined for each event. This also offers the possibility of improving our knowledge of the parton distribution functions (PDFs) of the proton, via exploring different phenomenologies in this colliders.

The further study of vector boson production can refine our understanding of the Standard Model (e. g., Tevatron measurements that have contributed in the development of LO & NLO theoretical predictions used today for LHC) and even open some doors towards physics beyond the SM.

Today, the focus of measurements of W and Z production at the LHC is to test the theory of perturbative Quantum-Chromodynamics (QCD) in different energy regimes, to provide better constraints on the parton distribution functions, and to improve electroweak precision measurements. Also, as W and Z production are dominant backgrounds to Higgs boson measurements and searches for physics beyond the Standard Model, these measurements will provide insight to these studies.

The structure functions of the proton, which are a dominant source of uncertainties in electroweak precision measurements at hadron colliders, can also be constrained through studies of the cross section ratio of W to Z bosons production due to the cancellation of uncertainties in the ratio calculation. In the plot shown below we see the cross section ratio for W^+ and Z from data experimental data against the theoretical predictions of different PDFs fits:

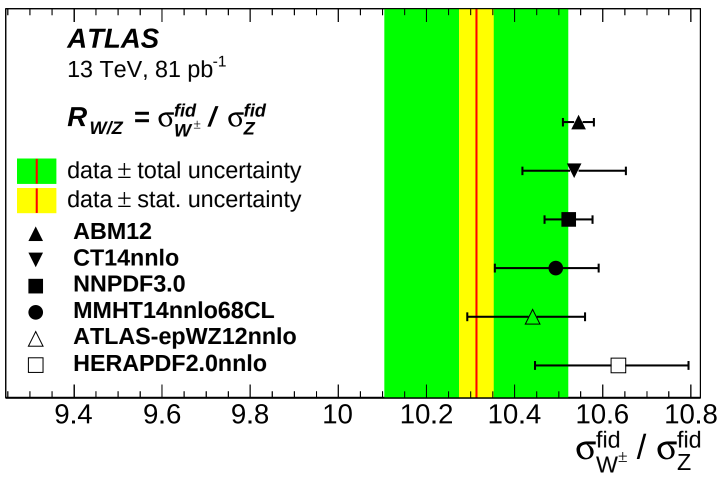

Figure 2: W^+ to Z fiducial cross section ratio againts PDFs fits predictions

2 ATLAS data analysis with ROOT

ROOT is an object-oriented program and library developed at CERN originally designed for particle physics data analysis. It contains several features specific to this field. Different parts of this abstract platform are a graphical user interface and a GUI builder, container classes, reflection, a C++ script and command line interpreter (CINT), object serialization and persistence. Using AnalysisBase 2.4.7 we process the event loop and select events form specific physics process such as the Z boson decay.

In the work presented in this report a program in ROOT has been used for the event selection from the data and Monte Carlo samples. First, the event selection criteria and some corrections introduced by the program will be presented. The code was provided by Mateusz Dyndal and was further modified. The behavior of the muon and electron channels will be compared via control plots of different distributions such as transverse momentum or invariant mass of an oppositely charged pair of either muons or electrons. Afterwards, the differences between the latest data reconstruction and its predecessor will be briefly analyzed, looking for significant changes that could improve the measurements. After some considerations, a re-weighting based on two distributions will be performed and its results shown.

2.1 Event selection criteria & Corrections

The experimental signature of Z bosons in the leptonic decay channel are two oppositely charged, isolated and energetic leptons. These leptons stem from the same vertex and form an invariant mass close to the Z boson mass of $m_Z = 91.2$ GeV. An event display of the typical $Z \to \mu\mu$ event candidate, recorded by the ATLAS detector for 7 TeV, is shown in the Figure :

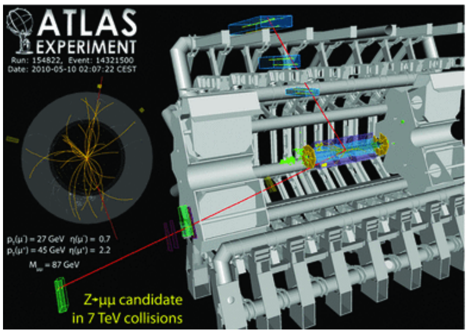

Figure 3: $Z \to \mu\mu$ event candidate as it passes through the detector

The event selection is performed through the use of a ROOT program mentioned before, that will also include some scale factors as corrections. Electrons and muons event candidates are selected using different trigger logic. For muon selection we apply HLT_mu50 or HLT_mu20_ilooseL1MU15. For electrons the logic differs for data and Monte Carlo applying for data e24_lhmedium_L1EM20VH or e60_lhmedium or e120_lhloose; and for Monte Carlo e24_lhmedium_L1EM18VH or e60_lhmedium or e120_lhloose. Electron and muon candidate events are selected using triggers which require at least one electron or muon with transverse momentum threshold of $p_T = 25$ GeV. A tracking-based gradient isolation requirement (based on the cone radius of ΔR in ATLAS beam coordinates) is imposed on both electrons and muons. Requiring isolation greatly reduces the number of particle jets which are misreconstructed. Both electrons and muons have to pass “medium” likelihood-based identification requirements. Muons are selected for $|\eta| < 2.4$ while electrons for $|\eta| < 2.47$ but the region $1.37 < |\eta| < 1.52$ is excluded. The interval $1.37 < |\eta| < 1.52$ contains the transition region between the barrel and endcap sections, a detector region in which cables and services lead to a lower quality of reconstructed clusters. We also apply some d_0 and z_0 cuts ... !!! The Z boson selection requires exactly two selected leptons of the same flavour and opposite charge, with invariant mass in the interval $66 < m_{ll} < 116$ GeV.

2.2 Data and Monte Carlo samples

The data used comprises five 2015 runs with tag numbers 286361, 286364, 286367, 286411, 286474. Three Monte Carlo samples are used for $Z \to ee$, $Z \to \mu\mu$ & $Z \to \tau\tau$ as follows:

- for electrons:
  mc15_5TeV.361106.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Zee.merge.
  AOD.e4916_s2860_r7856_r7676
- for muons:
  mc15_5TeV.361107.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Zmumu.merge.
  AOD.e4916_s2860_r7856_r7676
- for taus:
  mc15_5TeV.361108.PowhegPythia8EvtGen_AZNLOCTEQ6L1_Ztautau.merge.
  AOD.e4916_s2860_r7856_r7676

Background sources for $Z/ \to l^+l^-$ events stem from $Z \to \tau\tau$ events, di-boson events, $t\bar{t}$ decays and QCD multi-jet events. In this analysis only $Z \to \tau\tau$ events are included as background, as the di-boson and $t\bar{t}$ decays contribution is small compared to the signal and QCD contributions are negligible based on 7 and 13 TeV analysis. For data Monte Carlo comparison the Monte Carlo simulations are normalized to the luminosity of the data set, reported by *LumiCalc* to be 25.5 pb^{-1}.

Corrections

- The Powheg samples are scaled by a k-factor = 1.026, from NLO to NNLO correction.
- Every other factor introduced in the analysis follows the official 2015 factors for 13 TeV data.
- Trigger efficiency scale factors, reconstruction identification efficiency scale factor and isolation scale factor for muons and electrons are introduced.
- Muon momentum scale resolution corrections and electron energy scale resolution corrections.

Cut Flow

We now show cut flow histograms presenting the selection process of the program:

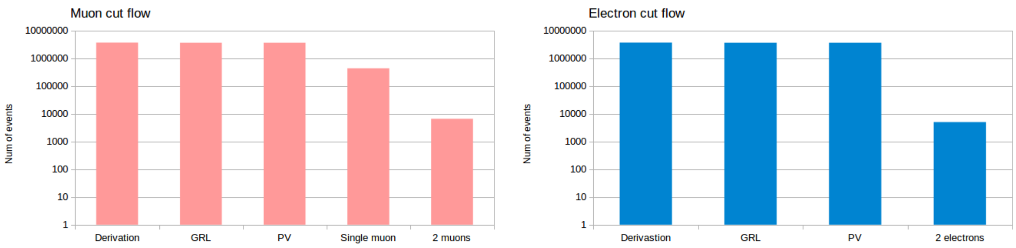

Figure 4: Muon(left) and Electron(right) Cut flow diagrams

The different labels stand for:
- *Derivation*: the number of events that pass the trigger, our initial number of events.
- *GRL*: good run list requirement; double check that the events selected are in the good run lists.
- *PV*: the events pass tracking and primary vertex requirements.
- *2 muons/electrons*: two oppositely charged muons or electrons that with masses around Z peak mass interval.

Control plots

The comparison of data and Monte Carlo for the η distributions is shown below:

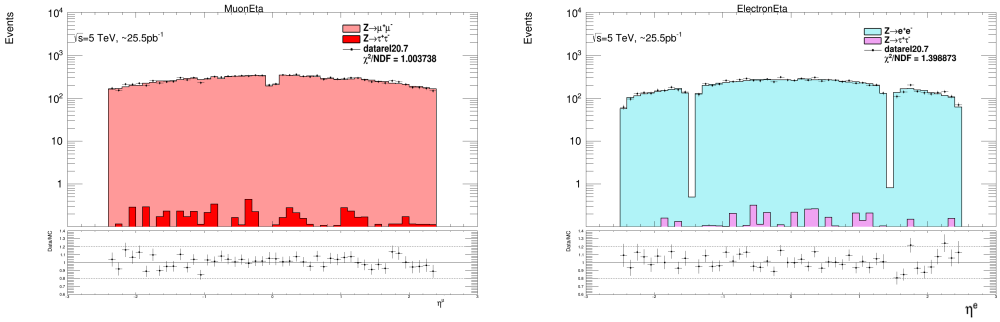

Figure 5: Distributions η^{μ}(left) & η^{e}(right)

The Monte Carlo properly describes the distribution for both muons and electrons. For the electrons the regions between endcap and barrel were we made our cuts in the selection are visible. We can also appreciate the $Z \to \tau\tau$ background included in the Monte Carlo, which is significantly smaller than the signal.

The comparison of data and Monte Carlo for the transverse momentum distributions is shown below:

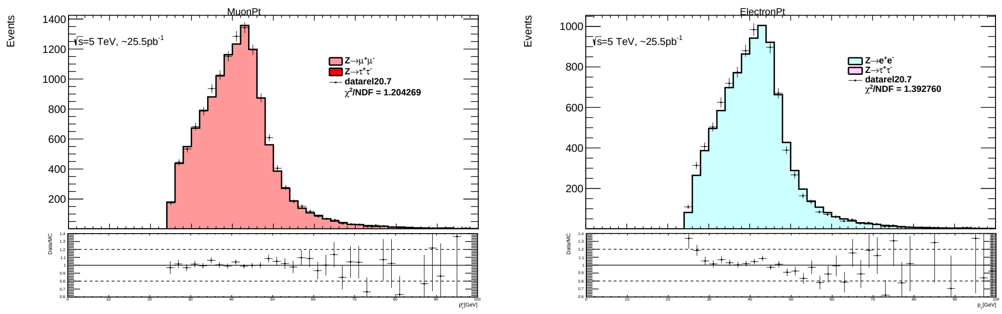

Figure 6: Transverse momentum distribution for muons (left) & electrons (right)

For the muon channel the Monte Carlo is correctly describing the data. In the electron channel we see a discrepancy apparent in the ratio plot.

The comparison of data and Monte Carlo for the di-lepton invariant mass distributions is shown below:

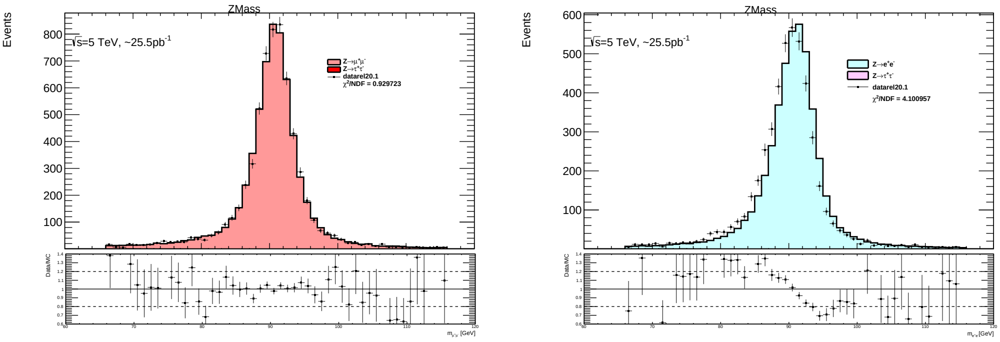

Figure 7: Invariant mass for di-muons (left) & di-electrons (right)

Here the distributions are shown for the older data (realease 20.1) . Di-muon invariant mass is well described by the simulation while di-electron mass is not. We hoped that the new data reconstruction might improve the di-electron mass distribution, but it did not significantly change them as shown below:

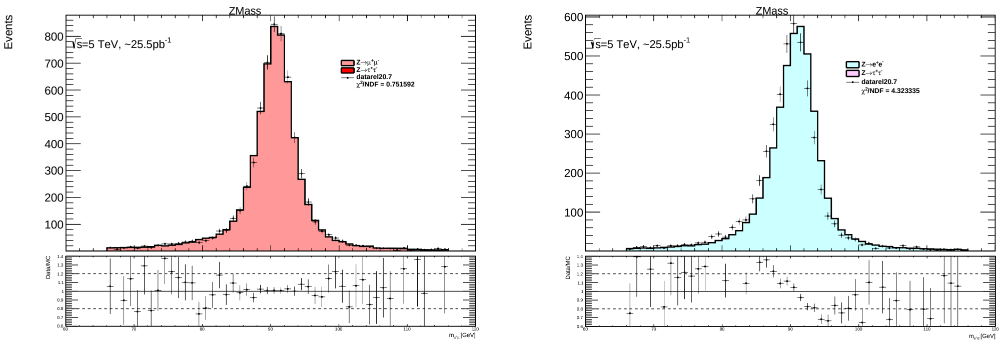

Figure 8: Invariant mass for di-muons (left) & di-electrons (right)

We still find the same behavior in the electron distribution for the new reconstruction. The observed pattern suggests the need of an additional energy scale correction. This discrepancies for the electron channel might be caused by the use of 13 TeV factors, an energy at which the pile up is considerably higher.

The comparison of data and Monte Carlo for z vertex distributions is shown below:

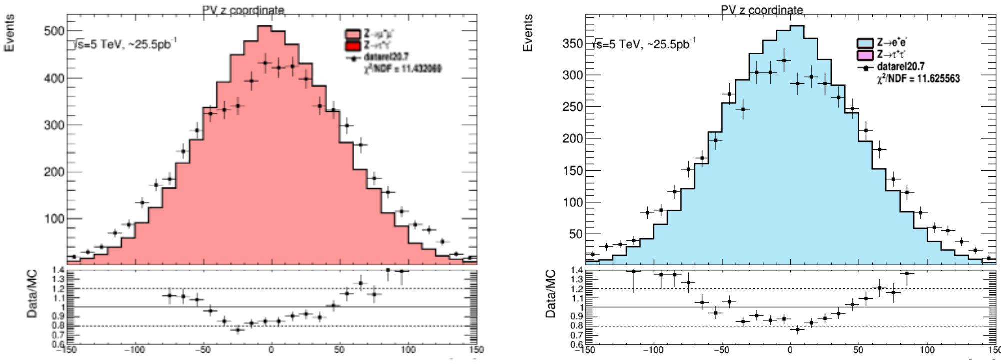

Figure 9: Z vertex coordinate for muons(left) & electrons (right)

The distributions for the old reconstruction are been shown. There is not good agreement between data and simulation for this distribution. It was hoped that the new reconstruction could improve this after introducing tracking calibrations and other corrections. As we see in the plots below for the new reconstruction we see no significant improvement:

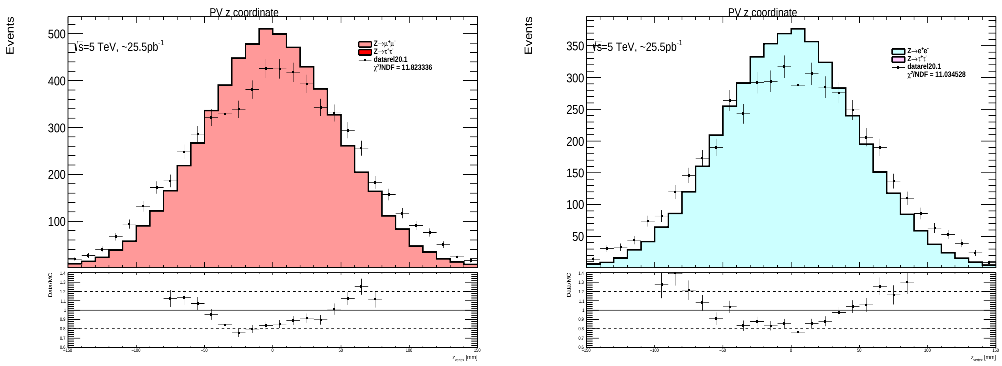

Figure 10: Z vertex coordinate for muons(left) & electrons (right)

The pile-up related distributions will be shown only for muons, as they are similarly behaved, and only for the last reconstruction data, as again we do not see significant changes. The $< \mu >$ factor distribution, average number of interactions per bunch crossing, will be shown beside the number of vertex(es) in Figure 11.

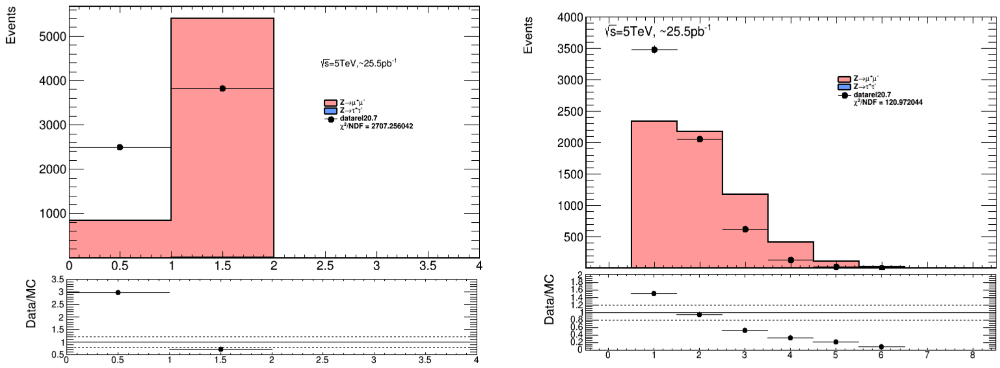

Figure 11: Muon distributions for $< \mu >$ (right) & Number of vertexes (left)

The discrepancies between data and simulation for pile-up related distributions could be improved by applying a reweighting of events. We will modify the code so it takes the data and simulation and it applies this reweighting process and analyze the changes.

Reweighting

The reweighted Monte Carlo samples improve the results for the number of vertexes distribution. This was expected as the two distributions are correlated.

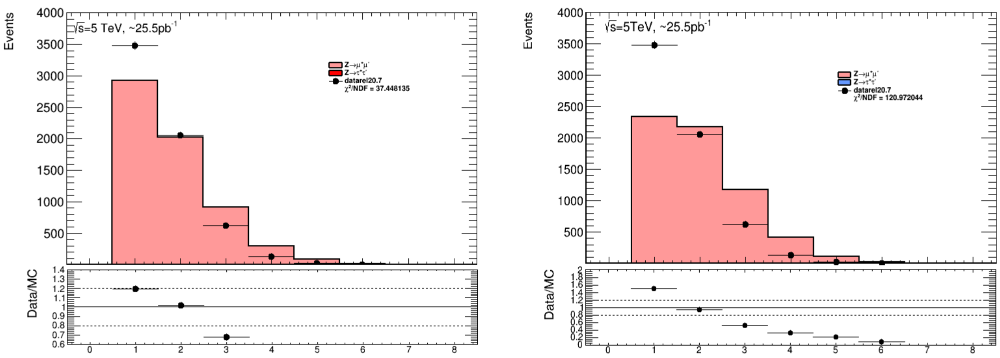

Figure 12: Number of vertexes distribution for muons before (right) & after (left) reweithing

We can clearly see in the ratio plot the improvement after the application of the reweighting. The rest of the analyze distributions do not show significant change after the process and thus will not be shown.

3 Conclusions

In the work presented in this report we have analyzed the Z boson decay process from 5 TeV data samples and compared it to the Monte Carlo Powheg+Pythia simulation for electron and muon channels. The muon channel is well described by the simulation samples for kinematic distributions and invariant di-lepton mass as we have shown and discussed in the control plots. The electron channel present some discrepancies in the transverse momentum distribution and the invariant di-lepton mass distribution. These discrepancies might arise from the usage of 13 TeV factors. We proposed as a possible solution the introduction of additional energy scale corrections for the electrons. Also, the new and old data reconstructions have been compared, concluding that there is no significant differences based on the χ^2 calculated for each distribution. The discrepancies encountered for pile-up distribution motivated the application of reweighting over the Monte Carlo to better suit the data. We observe better simulation data agreement in the number of vertex distribution after this procedure.

Acknoledgements

I want to thank my supervisor Ewelina Lobodzinska for her time and guidance during my work; Mateusz Dyndal for providing the program and helping me understand the code and the ROOT environment better; and special thanks to my supervisor Ksenia Gasnikova for her support and time answering my everyday questions. Last but not least, the opportunity offered to me by DESY to enjoy this summer student grant is highly appreciated.

References

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