Measurement of the cross sections of W and Z boson production and their ratios with the CMS experiment at $\sqrt{s} = 13.6$ TeV

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After highly successful data taking periods in the years 2010-2012 and 2015-2018, the LHC started its latest data taking phase in 2022. During the second long shutdown, parts of the LHC and the four big experiments were updated. Now, the LHC has been operating at the unprecedented center of mass energy of 13.6 TeV for more than two years.
To ensure a high quality of the new data after the updates, it is important to measure quantities that are well known in the Standard Model and have been measured many times in the past. Such key quantities are the cross sections of vector boson production and their ratios.

From an experimental point of view, studying vector boson production is highly interesting, as it combines measurements of all detector components. In an analysis of the leptonic vector boson decays, every part of the detector is involved: the tracker, both ECAL and HCAL, as well as the muon chambers. From the theoretical point of view, the measurement can become interesting as the high precision in the cross section ratios, may give rise to constraints on the parton distribution functions.
My work focused on the vector boson decay into well-identified and isolated muons with at least 25 GeV transverse momentum. The Z boson acceptance region is defined by the presence of two opposite-sign muons, which have a dimuon mass between 60 and 120 GeV, whereas the W boson acceptance region is defined by the presence of only one muon. The very first good dataset taken in 2022 was used for the measurement, corresponding to an integrated luminosity of 5.01 fb^{-1}.
The measurement of Z boson production is performed using the dimuon mass distribution, while the W measurement is done using the transverse mass. This approach addresses the key difference between the Z and W boson, the Z boson decaying into two muons, while the W boson decays into a muon and a neutrino. Since the neutrino cannot be measured with the CMS detector, the only piece of information can be constructed in the direction transverse to the beam, where the total momentum is zero before the collision and therefore must be zero afterwards as well.
The different regions are then evaluated using a combined binned profile likelihood fit, where the theory expectation comes from simulated events. Even though the simulation excels at modeling data, there are residual differences to data in the pileup description, the boson transverse momentum modeling, as well as scale and resolution of the reconstructed objects. These differences are mitigated using data driven approaches in order to further optimize the measurement's precision.
In the W region, which is defined by the presence of one well-identified and isolated

muon, there is a significant contribution from QCD multijet processes. These may have a signature similar to that of the W bosons, if a muon with large momentum is produced from electroweak processes within a jet. As the simulation of this particular background is challenging, a data driven approach is applied to estimate the QCD multijet background.

The uncertainties on the cross section results are dominated by the 1.4 % luminosity uncertainty, which cancels for the cross section ratios. Here, the total uncertainty is well below 1 % and dominated by the uncertainties on the muon efficiency, QCD estimation and MC sample size. To validate theory calculations with this measurement, the cross sections and their ratios are calculated using DYTurbo at NLO in QCD with different pdf sets. The Standard Model predictions are found to be consistent with the measurement.

Returning to the goals of the analysis, the data quality, within the limitations of both theory and measurement, appears to be excellent, showing no deviation from the expectations at the new center-of-mass energy of 13.6 TeV.