Abstract

Precise measurements of the cross sections of the rare processes with final states composed of the top quark(s) and bosons are vital because they test the Standard Model predictions by probing the top-boson electroweak couplings. Besides, such measurements improve background estimation in some of the direct Beyond the Standard Model searches. This dissertation thesis presents the refined measurement of the associated production of the top-quark pair and Z boson ($t\bar{t}Z$) performed by the ATLAS collaboration. It refines the previous ATLAS $t\bar{t}Z$ measurement which is also based on the full Run II dataset recorded by the ATLAS detector in proton-proton collisions at $\sqrt{s} = 13$ TeV at the Large Hadron Collider from 2015 to 2018. The refined measurement benefits from the inclusion of the all-hadronic $t\bar{t}$ decay channel, improved methodology and the latest ATLAS precision recommendations. This thesis focuses on the inclusive cross section measurement in the tetralepton channel and on the regularised differential measurements in the combination of the trilepton and tetralepton channels. The tetralepton channel is characterised by the leptonic decays of both the $t\bar{t}$ pair and Z boson, while in the trilepton channel there is only one charged lepton from the $t\bar{t}$ decay. The key improvement in the tetralepton channel is the use of neural networks for signal-background separation. Since the background contribution is effectively suppressed with the neural networks, the selection criteria are loosened and, consequently, the signal acceptance is increased. The cross section is extracted with profile-likelihood fit. The measured inclusive tetralepton cross section $\sigma^{4\ell}_{t\bar{t}Z} = 0.97 \pm 0.11\,(\text{stat.}) \pm 0.05\,(\text{syst.})$ pb is consistent with the latest Standard Model prediction. This result is discussed in the context of the final total inclusive cross section obtained in the refined $t\bar{t}Z$ measurement from a combined profile-likelihood fit which uses the optimised setup for the individual channels. The final total inclusive cross section is measured with the relative precision of 6.5% what represents 35% improvement compared to the previous ATLAS measurement and surpasses the relative theory precision of 10%. The differential cross sections are in the refined $t\bar{t}Z$ analysis measured with a novel profile-likelihood unfolding technique which has systematic uncertainties deeply rooted in its formalism, allows for unfolding from multiple detector-level regions and enables to constraint background processes by extracting their normalisations from dedicated control regions. Regularisation is employed for six variables which require reconstruction of hadronically decaying top quark from jets. Regularisation suppresses large fluctuations that would otherwise emerge from the non-diagonal migration matrices for these variables. The six regularised differential measurements probe the kinematics of the $t\bar{t}Z$ system and are also sensitive to the operators of the Standard Model Effective Field Theory. Both absolute and normalised differential cross sections measured at both particle and parton level for all regularised variables are statistically limited.

Keywords: $t\bar{t}Z$ associated production, top quark, Z boson, ATLAS, LHC, particle physics