Search for tWZ in proton-proton collisions at $\sqrt{\mathrm{s}} = 13$ and 13.6 TeV with the ATLAS Experiment

Carolina Costa

Universität Siegen

The ambitious goal of high-energy particle physics is to understand nature at its most fundamental level. The Standard Model (SM) of particle physics is the framework used to describe these particles and their interactions. While extraordinary accurate, the SM still leaves many questions unanswered - such as the nature of dark matter or the matter-antimatter asymmetry. These phenomena can only be explained by the presence of new physics; however, no evidence of such has yet been discovered.

One particle that can be a door for probing for new physics is the top quark. This particle is the heaviest elementary particle known and has by far the largest strong coupling to the Higgs boson. Thus, it is believed to play a special role in the structure of the SM.

The tWZ channel provides an excellent probe of the SM: it is sensitive to the coupling between the top quark and the Z boson, as well as to the coupling between the W and Z bosons. Furthermore, it is a relevant background to other processes involving top quark production and bosons.

The tWZ process at the ATLAS Detector

My doctoral project focuses on the first search for tWZ channel with the ATLAS detector. The ATLAS detector is the largest general-purpose detector at the Large Hadron Collider (LHC), designed for precise measurement of the particles produced in those collisions. Analysing the high-precision data collected from those collisions provides the opportunity to probe the SM predictions and find new particles predicted (or not) by BSM theories.

Since it started operations in 2009, the LHC has undergone multiple operational runs, with its third run lasting from July 2022 to June 2026. During Run-3, the highest collision energy to date was achieved, with a centre-of-mass energy of $\sqrt{s} = 13.6$ TeV. My analysis uses a subset of the Run-3 dataset, exploiting the higher centre-of-mass energy to pursue the first observation of tWZ production and to use this channel as a probe of BSM physics.

In the SM, the tWZ interaction occurs at first order when a top quark is produced in association with a W boson, and subsequently a Z boson is radiated from either the initial-state bottom quark or from the final state W boson or top quark. The tWZ process has a small production cross section of $\sigma = 148^{+10}_{-9}\ fb$ at $\sqrt{s} = 13.6TeV$ [1].

In addition to the small cross-section, it is a difficult process to observe because of the large background contributions from processes with similar topologies, most notably the production of top quark pairs with a Z boson ($t\bar{t}Z$), with a production cross section 7 times larger, and process involving two bosons (ZZ, WZ) that decay leptonically, making its observation experimentally challenging.

Due to the tWZ small cross-section and large backgrounds, only two final-state topologies are experimentally feasible for a cross section measurement, the tri- and tetra-leptonic states, as they provide the cleanest experimental signatures. Examples of diagrams for this process are shown in Figure 1.

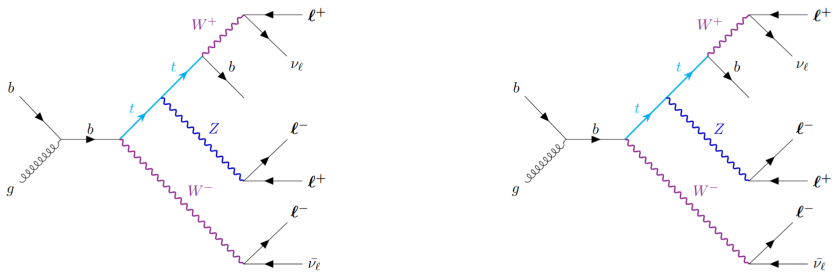

Figure 1: Example of Feynman diagrams for tWZ processes, for tri-leptonic (left) and tetra-leptonic (right) decays. The Z boson decays to two leptons ($Z \to \ell\ell$), where lepton (ℓ) refers to an electron or a muon; the $t \to Wb, W \to \ell\nu$ decay yields another charged lepton; the other W boson can either decay hadronically ($W \to q\bar{q}$ in the diagram of the left) totalling 3 final-state leptons or leptonically ($W \to \ell\nu$ in the diagram of the right) totalling 4 final-state leptons. Jets arise from the hadronisation of a bottom quark (b-jet) and two light jets ('q' in the figure).

Because the tWZ signal is rare and its final states overlap strongly with background processes, multivariate analysis techniques are an important component of the measurement. I am currently training a Deep Neural Network model for signal-background separation, using the multi-variable kinematic information of the final-state objects. This allows for greater discriminating power between signal and background, improving the sensitivity to the tWZ signal.

References

[1] CMS Collaboration. *Observation of tWZ production at the CMS experiment.* 2025. arXiv: 2510.19080 [hep-ex]. URL: https://arxiv.org/abs/2510.19080.