Searching for subtle signs of new physics via novel top quark measurements

This letter describes a programme of experimental particle physics research undertaken by the University of Cape Town and IFIC Valencia ATLAS groups that commenced in 2020. The programme is concerned with the electroweak couplings of the top quark as they pertain to the search for new physics and comprises analyses of data within the ATLAS collaboration and reinterpretation of published LHC data outside experimental collaborations. We hope to highlight the importance of a thematic long term research programme in enriching the African particle physics community and maximising its impact on the field's most prominent research questions.

No evidence of direct production of new light states has been observed in the LHC data. Thus attention has naturally turned to scenarios of new physics in which the new states have masses at an energy scale Lambda that is so large in comparison to the scales directly probed at the LHC that direct production of these states in LHC collisions is kinematically suppressed. Significant deviations of measurements of the SMEFT coefficients from the SM expectation may be the first evidence of new physics and would constitute a major discovery. The top quark is involved in many scenarios of new physics [1-4]. As the African particle physics community prepares for the unprecedented datasets of the HL-LHC it is crucial to identify previously unexplored measurements that have the potential to improve the precision at which SMEFT coefficients can be determined. Through execution of such measurements and their interpretation in the SMEFT, the African particle physics community can maximise its impact on the HL-LHC programme.

Recent data from the LHC allow for a robust and precise characterisation of the electroweak interactions of the top quark [6]. State of the art inclusive and differential cross section measurements of the associated production processes of top quarks and neutral gauge bosons, using LHC data allow to further study the top quark electroweak couplings and set constraints on several EFT operators. The combination of numerous observables allows constraints so-called *blind directions* in the SMEFT parameter space. Blind directions refer to linear combinations of SMEFT coefficients that, due to cancellation effects between parameters, remain entirely constrained by analyses that utilise limited sets of LHC data even when individual parameters appear constrained. This emphasises the need for global analyses that consider vast arrays of experimental results simultaneously.

The tWZ process refers to the rare electroweak production of a single top quark in association with a W boson and a Z boson. The tWZ process is sensitive to multiple SMEFT operators. The advantages of tWZ measurements in constraining the SMEFT coefficients are detailed in [5]. The effect of the SMEFT operators on the tWZ process shows an energy dependence that is more pronounced than that of alternative processes such as tZq. Thus constraints on SMEFT coefficients from tWZ will continue to improve after constraints from processes with weaker energy dependence become systematically limited. We identify differential measurements of the tWZ process as an example of a research goal in which the African community can have a unique impact on the search for new physics at the HL-LHC.

The results of the analyses fully detailed in [6] and [7] are summarised in Figure 1. The figure shows examples of the confidence intervals on the CtZ and CtW SMEFT coefficients from a fit to a range of top quark measurements based on LHC Run-II data [6]. Similarly the figure shows credible intervals on a set of coefficients that includes CtZ and CtW that are expected to be obtained from a single measurement of the differential cross section of the tWZ process with the full HL-LHC dataset [7]. These plots emphasise the qualitative and quantitative complementarity of the measurement of top quark related processes as a means of constraining the SMEFT.

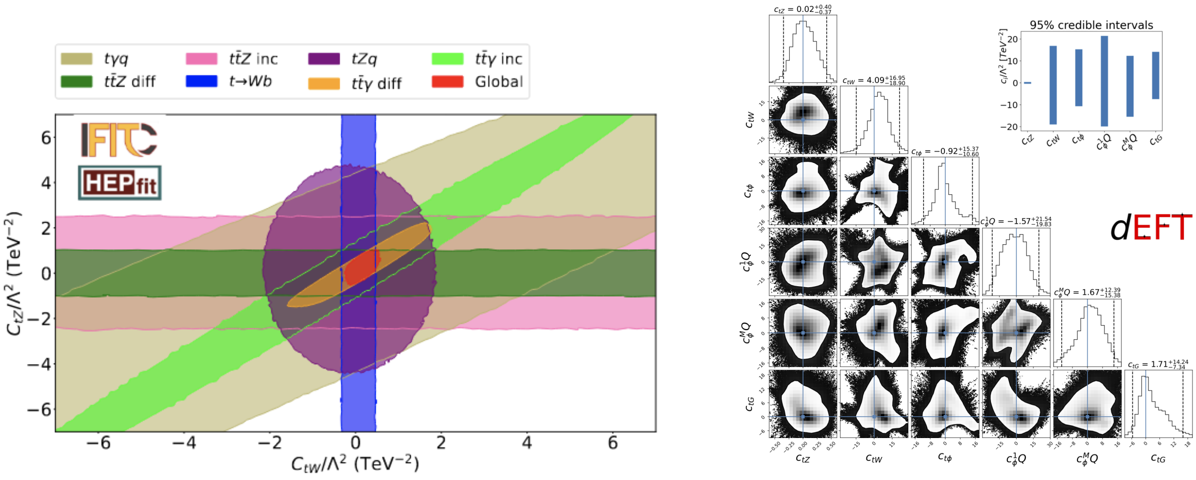

Figure: 1 In the left-hand plot, the confidence intervals on the CtZ and CtW SMEFT coefficients are illustrated as regions in the corresponding 2-D parameter space obtained from a fit to a wide range of top quark measurements based on LHC Run-II data. In the right-hand plot 1- and 2-D marginalised credible intervals on a set of coefficients that includes CtZ and CtW that are expected to be obtained from a measurement of the differential cross section of the tWZ process with the full HL-LHC dataset.

To conclude this letter, we discuss our progress so far in the long term project of devising and executing novel top quark measurements to constrain the SMEFT. In 2020, the UCT and IFIC established a collaboration to measure, for the first time, the leptonic charge asymmetry in the ttW process using the full Run-II data of the ATLAS experiment. The inclusive and differential ttW cross sections are sensitive to SMEFT coefficients. The ttW measurements has gone from a novel idea to a full-fledged ATLAS analysis that has recently entered the formal ATLAS approval process. We hope that the ttW project is the first step in a long and fruitful collaboration that yields an unprecedented African impact on the LHC physics programme.

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