2023 Summer student internship report “Review of rare exclusive few-body decays of the Higgs, Z, and W bosons, and the top quark”

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1 Brief summary

The present study involves the compilation and systematic organization of hundreds of rare exclusive few-body decays of Higgs (H), W, Z, and top quarks. A rare exclusive decay implies that the branching ratio is less than 10^{-4}. We study decays into few-body final states with 2 to 4 particles maximum. The primary objective of this work is to provide a comprehensive reference for these rare decay processes and investigate different theoretical approaches that describe these decays. In addition to the compilation, an attempt has been made to simulate the Higgs boson decay to virtual top quarks, $h \to t^{*}\bar{t}$ and $h \to t^{*}\bar{t}^{*}$ decay processes, as a function of the Higgs mass, using the MadGraph@MC code, but it was unsuccessful due to the difficulty separating signal and background interference channels. Nonetheless, in the process of doing so, I improved my knowledge of MadGraph@MC, and collider physics in general, and I learned how to use the CERN Linux system (lxplus), and how to submit jobs on the CERN batch system.

2 Compilation of Exclusive Few-Body Decays

The first step of the project involved an extensive literature review to gather the relevant theoretical studies of exclusive few-body decays of H, W, Z, and top quarks. Various sources, including published research articles, conference proceedings, and particle physics databases, were consulted to collect the necessary data. The decays with branching ratios less than 10^{-4} into 2 to 4 final particles were identified as exclusive and were considered for compilation. The steps are taken as below:

- Data preparation: I collected the data from various sources and compiled them into CSV files. Each CSV file contained specific information about the different decay processes, including decay modes, branching ratios, uncertainties, theoretical framework, and bibliographical references.
- Grouping, sorting combined with regex processing: I grouped the data based on specific criteria, such as final-state particles or theoretical models, to create separate tables. Sorting

the data within each group to ensure a physically logic order. I used regex to extract specific information from the data, representing it in a more detailed way.

- Based on the branching fraction of each decay mode and on the expected integrated luminosities to be collected in e^+e^- collisions at the Future Circular Collider (FCC-ee) at the Z boson pole, the WW threshold, the Higgsstrahlung, and $t\bar{t}$ runs, I identified those decays that are potentially observable at the FCC-ee.

- Turn data frame into LaTeX format: I used a few manipulation tricks to have the final step of generating a LaTeX table can be done in one single line of code 'pd.style.to_latex()'

- Paper writeup: I scoured through referenced papers and summarized the different theoretical approaches to compute such decays. The strengths, weaknesses, and possible applications of each approach are discussed to provide a clear understanding of their relevance in describing rare decay phenomena.

The compiled data were meticulously organized into separate LaTeX tables, with each table representing different groups of decay processes based on the nature of the final-state particles and the involved theoretical models. The tables include information such as decay modes, branching ratios, uncertainties, theoretical framework, and references to the original sources.

3 Results

The detailed results of this research project are being written down in a scientific article that will be submitted for publication [1].

References

[1] D. d'Enterria and Van Dung Le. "Review of rare exclusive few-body decays of the Higgs, Z, and W bosons and top quark". to be submitted. 2023.