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Go with the Flow

Normalizing Flow applications for High Energy Physics

Referees: Prof. Dr. Jan-Martin Pawlowski
Prof. Dr. Monica Dunford (?)

Abstract

bla bla

Zusammenfassung

bla bla Auf Deutsch

Contents

Preface

The research presented in this thesis was conducted at the Institute for Theoretical Physics at Heidelberg University from February 2019 to February 2022. The contents of the Chapters **??**-**??** are based on work in collaboration with other authors and have previously been published as

[1] M. Bellagente, A. Butter, G. Kasieeczka, T. Plehn and R. Winterhalder,
"How to GAN away Detector Effects",
SciPost Phys. **8** (2020) no. 4, 070, `arXiv:1912.00477 [hep-ph]`

[2] M. Bellagente, A. Butter, G. Kasieeczka, T. Plehn, R. Winterhalder, L. Ardizzone and U. Köthe,
"Invertible networks or partons to detector and back again",
SciPost Phys. **9** (2020) 074, `arXiv:2006.06685 [hep-ph]`

[3] M. Bellagente, M. Luchmann, M. Haußmann and T. Plehn,
"Understanding Event- Generation Networks via Uncertainties",
`arXiv:2104.04543 [hep-ph]`

[4] R. Winterhalder, M. Bellagente, and B. Nachmann
"Latent Space Refinement for Deep Generative Models",
`arXiv:2106.00792 [stat.ML]`

1 | Introduction

The motivation behind the prediction of a fundamental scalar particle in the Standard Model (SM), the Higgs boson, was to grant a mechanism for the generation of the masses of the electroweak gauge bosons via electroweak symmetry breaking (EWSB) [?, ?, ?]. The discovery of a Higgs boson at the Large Hadron Collider (LHC) [?, ?] strongly hints at EWSB indeed being the mechanism behind the mass generation of the SM particles. One of the pivotal tasks of the LHC and future colliders is to probe both the local and global structure of the Higgs potential, which is reflected in the couplings of the Higgs boson to other SM particles and in its self-coupling, respectively. In this thesis, we present a global view on Higgs couplings at the LHC to extend our understanding of the EWSB sector and to set universal constraints on new physics that might be hiding in it.

Driven by the question what current data reveal about the EWSB sector and new physics that might be hiding in it, in this thesis we aim at increasing the precision of Higgs-coupling measurements and combining them in a comprehensive framework. This requires us to rethink the way we perform, interpret and combine experimental analyses in a way that fully exploits the available data. To tackle this challenge, we take a multi-prong approach: First, we focus on the improvement of an individual Higgs-production and decay channel by applying modern analysis techniques. Second, we perform global analyses of the Higgs-gauge sector for the LHC and a potential future upgrade of the LHC in a model-independent framework.

Motivated by the experimental advances of LHC Run II, we perform a global fit of the Higgs-gauge sector based on Higgs and di-boson measurements as well as electroweak precision data in Chapter **??**. We include momentum-related kinematic distributions and examine the impact of the different LHC Run II measurements on the reach of our global analysis in detail. On the theory side, we broaden our view on the Higgs sector by expanding the set of considered dimension-six operators from 10 to 18 with respect to previous SFitter analyses [?, ?]. This extension of our operator set will bring us a significant step closer to a global SMEFT fit at dimension six. We discuss how the additional fermionic Higgs-gauge operators have a relevant impact on a global fit of the Higgs-gauge sector despite the strong constraints from electroweak precision data.

In Chapter **??**, we will summarize our results and give an outlook to further improvements and extensions of the concepts discussed in this thesis. Each of the lines of research mentioned above will aid in constructing a global view of Higgs couplings at the LHC as well as its proposed future upgrade and will bring us one step closer to probing if EWSB is indeed described by the simple structure of the SM Higgs potential. The derived limits on Higgs couplings in the SMEFT framework can be mapped onto constraints for UV-complete BSM models [?, ?]. Furthermore, they provide a key ingredient for future tests of the global structure of the Higgs potential. In summary, the thorough investigation of Higgs couplings at the LHC is crucial to gain a deeper understanding of the structure of the Higgs sector and EWSB on a fundamental level.

2 | Generative Models

bla

3 | Unfolding in particle physics

bla

4 | GAN unfolding

LHC analyses directly comparing data and simulated events bear the danger of using first-principle predictions only as a black-box part of event simulation. We show how simulations, for instance, of detector effects can instead be inverted using generative networks. This allows us to reconstruct parton level information from measured events. Our results illustrate how, in general, fully conditional generative networks can statistically invert Monte Carlo simulations. As a technical by-product we show how a maximum mean discrepancy loss can be staggered or cooled.

5 | INN unfolding

Abstract

For simulations where the forward and the inverse directions have a physics meaning, invertible neural networks are especially useful. A conditional INN can invert a detector simulation in terms of high-level observables, specifically for ZW production at the LHC. It allows for a per-event statistical interpretation. Next, we allow for a variable number of QCD jets. We unfold detector effects and QCD radiation to a pre-defined hard process, again with a per-event probabilistic interpretation over parton-level phase space.

6 | Bayesian Neural Networks

bla bla

7 | Latent Space Refinement

8 | Summary