HHH workshop

Monday 29 September 2025 - Wednesday 1 October 2025

Dubrovnik

Book of Abstracts

Contents

Experiment session / **3**

Monte Carlo Simulation for the LHC Experiments at CERN: A Comprehensive Overview

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This overview of the Monte Carlo (MC) simulation process at the four main experiments - ATLAS, CMS, ALICE, and LHCb - at the Large Hadron Collider (LHC) is provided in this talk. Given the complexity and noise of proton-proton collisions, simulated samples are essential for understanding and interpreting the experimental results, enabling precise measurements and searches for new physics. The general simulation workflow consists of three main stages: event generation, detector simulation, and digitization. This process is explored in all four experiments, identifying both shared methodologies and experiment-specific adaptations. Key software tools such as PYTHIA for event generation, GEANT4 for particle tracking, and dedicated experiment frameworks are discussed. In addition to highlighting the technical process, the presentation also addresses computational resources and the time required for these simulations. Looking ahead, the upcoming High-Luminosity LHC (HL-LHC) will amplify these challenges, necessitating improvements in the efficiency and scalability of simulation tools. This presentation aims to offer a structured understanding of LHC data simulation and its future directions.

Theory session / **4**

Multi-Higgs production as probes of HEFT interactions

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Using the framework of the Higgs Effective Field Theory (HEFT), I will discuss multi-Higgs production via gluon-gluon fusion (ggF) and weak boson fusion (WBF). For ggF-induced multi-Higgs production, I will highlight the impact of one-loop HEFT modifications on the Higgs self-couplings and study their effects on the production rates. By including these one-loop radiative corrections and going up to $\mathcal{O}(p^4)$ in the momentum expansion, we provide a detailed motivation of the parameter range that the LHC (and future hadron colliders) can explore through accessing these non-standard coupling modifications and momentum dependencies that reveal Higgs boson non-linearities.
In the second part of the talk, I will focus on multi-Higgs interactions with massive gauge bosons, parameterised within the HEFT framework, and discuss multi-Higgs processes via WBF. I will specifically highlight the enhancement of WBF triple Higgs production at the LHC and future colliders from the perspective of unitarity and demonstrate the radiative stability of such analyses under QCD corrections at hadron colliders. Taking unitarity bounds into account, I will discuss the expected sensitivity to electroweak triple Higgs production, considering $HHVV$ and $HHHVVV$ effective couplings at future colliders.

Theory session / **5**

Reinterpreting the ATLAS HHH search in CheckMATE and Rivet

Authors: Andrzej Konrad Siodmok[1]; Krzysztof Rolbiecki[2]; Tomasz Procter[1]

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We present early results from the reinterpretation of the ATLAS HHH search in CheckMATE and Rivet, including extensive validation material, and demonstrate how this can be used to place limits on a wider range of models than those studied by ATLAS.

Experiment session / **7**

Recent ATLAS HH results

Experiment session / **8**

Recent CMS HHH results

20'+10'

Experiment session / **9**

ATLAS Xbb tagging

Opening session: experiment and theory overview / **10**

Experimental overview: HHH and HH results since the 2023 HHH workshop

30' + 15'

Closing session: overview and vision for the future / **11**

HHH 2025 workshop: closing session and vision for the future

30'+15'

Experiment session / **12**

Ideas for HHH4b2tau

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CMS tau-identification in the context of HHH4b2tau

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ATLAS b-jet trigger

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CMS: small and large-radius jets tagging in searches for rare processes

20'+10'

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CMS: recent developments in heavy flavor tagging

Experiment session / **18**

ATLAS HHH6b

20'+10'

Theory session / **19**

An analytic result for the 0 → g g H H H 0→ggHHH amplitude

We present a fully analytic calculation of the leading-order one-loop amplitude for triple Higgs production via gluon fusion, gg to HHH, retaining full dependence on the mass of the heavy quark circulating in the loop. This amplitude provides a direct probe of the triple and quartic Higgs self-couplings, the measurement of which is a central goal of current and future colliders. The amplitude can be presented in compact form thanks to the use of analytic reconstruction techniques, based on finite-field and p-adic evaluations, partial fraction decompositions, and primary decompositions to identify common numerator factors. Our results provide a compact and efficient representation of the matrix element for this process, enabling evaluations that are more than an order of magnitude faster than existing numerical alternatives.

Theory session / **20**

Deciphering the CP nature of the 95 GeV Higgs boson

The excesses observed by CMS in the ττ and γγ channels around 95 GeV, together with the bbbar excess reported by the LEP collaboration in the same mass region, have sparked significant interest in the possibility of new physics beyond the Standard Model (BSM). Several BSM frameworks featuring a non-standard Higgs-like state lighter than 125 GeV have been proposed to explain the anomalies observed around 95GeV.Notable among them are the two Higgs doublet model (2HDM) with specific Yukawa textures, as well as minimal extensions of the 2HDM.As all these frameworks include in their particle spectra a CP-even and a CP-odd scalar, or as well as possible mixtures thereof, determining the CP nature of the 95 GeV Higgs state becomes crucial.
In this talk, I will address the problem of determining the CP nature of the 95 GeV resonance within a simplified model. Where the additional scalar state of mass 95 GeV has Yukawa couplings, scaled by the SM Yukawa coupling, and the interaction Lagrangian is constructed to include both scalar and pseudoscalar components, which can be tuned to a particular CP state through an appropriate mixing angle. Assuming that the 95 GeV anomalies persist in the high-luminosity phase of the LHC, I will demonstrate that the ττ decay mode of the 95 GeV Higgs-like state can serve as a unique probe of its CP nature, distinguishing whether it is a CP-even, CP-odd, or a CP-mixed state.

Theory session / **21**

Connecting Multi-Higgs production and the Electroweak Phase Transition

Exploring the Higgs sector via multi-Higgs production searches is a main goal for run-3 and high-lumi LHC. Can these searches inform us about the electroweak phase transition and matter-antimatter asymmetry? We address this question in the context of the TRSM (Two-Real-Singlet Model), which has known benchmark points enhancing multi-Higgs production. We update the triple-Higgs production benchmark points to include refined perturbativity bounds and explore the type of electroweak phase transition that occurs in the early universe; whether continuous or the first-order discontinuous phase transition desired for matter-antimatter asymmetry. After presenting our work, I outline lessons on correlating the type of electroweak phase transition and the enhancement of di-Higgs or triple Higgs production, highlighting the importance of the theory's vacuum expectation value of today and the symmetries of the model.

Theory session / **22**

Electroweak Symmetry Restoration at High Energies

With the milestone discovery of the Higgs boson at the LHC, detailed study of its properties becomes a high priority for collider physics. After a brief overview of the properties of the longitudinal gauge bosons and the Higgs boson, we revisit the Goldstone boson equivalence theorem and define the "electroweak symmetry restoration"(EWSR) quantitatively. We present some examples to examine the EWSR via the processes with "radiation amplitude zeros"by separating out the gauge sector and the scalar section. Finally, we comment on what we learn from testing the EWSR, and make some remarks on the SM at high energies in light of the UV completion.

Theory session / **23**

Triple Higgs production in a 100 TeV collider

In this talk we will discuss the feasibility of detecting triple Higgs production at a 100 TeV proton-proton collider. The final state considered will be that where each Higgs decays into a bottom-anti bottom pair. The study will be done within the SM as well as considering anomalous couplings which can be induced by New Physical effects.

Theory session / **24**

Detecting P-even CP violation at future colliders in the production of multiple Higgs bosons of extended Higgs sectors

New sources of neutral scalar-mediated CP violation that arise in extended Higgs sectors can originate in the Yukawa sector or in the structure of the scalar potential. Most treatments in the literature focus on CP-violating Yukawa interactions of neutral scalars, which is an example of P-odd CP violation since it derives from the mixing of two C-even operators of opposite sign P. In contrast, CP-violation arising from the scalar potential is P-even CP-violation, which can be observed by detecting three bosonic processes (suitably chosen) that are incompatible with the presence of a CP-symmetric scalar potential and/or vacuum. The discovery potential of such signals at various future multi-TeV lepton (and $\gamma\gamma$) colliders is assessed. The potential for detecting loop-induced P-even, CP-violating phenomena is also considered.

Opening session: experiment and theory overview / **25**

Theory overview

30'+15'

Experiment session / **26**

Open discussion for HHH YR5 contributions

Experiment session / **27**

CMS road to HH

Opening session: experiment and theory overview / **28**

Welcome talk + logistics

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TRSM Light Scalars in the Spotlight of the LHC

Theory session / **30**

A new probe of the quartic Higgs self-coupling