# T 70: Higgs: Decay into fermions II

Time: Thursday 16:30–19:00 Location: H-HS I

T 70.1 Thu 16:30 H-HS I

**Tau decay mode splitting in the semi-leptonic final state of the $H \to \tau\tau$ coupling measurement at ATLAS** — •Lara Katharina Schildgen, Philip Bechtle, Klaus Desch, Christian Grefe, Michael Hübner, and Peter Wagner for the ATLAS-Collaboration — University of Bonn

The Higgs decay to fermions plays an important role to gain a deeper understanding of the coupling properties of the Higgs. Due to its relatively high branching ratio and its distinct signatures, the decay of the Higgs boson to a tau lepton pair is a unique channel to access the Higgs-Yukawa coupling to fermions and is the first fermionic channel which has been observed by ATLAS and CMS with a significance exceeding $5\sigma$.

Because of its short lifetime, the tau lepton decays before reaching the detectors and is therefore reconstructed by its decay products. The reconstruction algorithm for hadronically decaying taus used in ATLAS for Run-2 benefits from an improved tau decay mode classification and higher energy resolution.

The presentation outlines the main effects of tau decay mode splitting in the $H \to \tau\tau$ coupling measurement in the semi-leptonic final state using the full Run-2 dataset collected at a centre-of-mass energy of 13 TeV.

T 70.2 Thu 16:45 H-HS I

**Optimizing the Machine Learning techniques used in the CMS Higgs→ $\tau\tau$ analysis** — •Maryam Bayat Makou, Elisabetta Gallo, Teresa Lenz, Mareike Meyer, and Alexei Raspereza — Deutsches Elektronen-Synchrotron DESY, Hamburg,Germany

One of the main goals of LHC experiments is the precise measurement of the Higgs boson's production properties in order to clarify its coupling structure. In Standard Model physics the coupling of the Higgs boson to fermions are introduced as Yukawa couplings. Due to the high branching ratio of the Higgs boson decay into tau leptons and the lower background contribution compared to H→ $b\bar{b}$ , the Higgs→ $\tau\tau$ channel is an interesting channel to probe the Higgs coupling to fermions.

The presented measurement is performed using data collected by the CMS experiment at a center-of-mass energy of 13 TeV in 2018 corresponding to an integrated luminosity of 59.7 $fb^{-1}$. The analysis is based on a multi-class neural network, which classifies the events into two signal classes (gluon-gluon and vector boson fusion production) and several background classes.The $e\mu$ final state of the tau lepton pair is studied. The main challenge in the analysis is the differentiation between the signal events produced via gluon-gluon fusion and the irreducible background process where a Z boson decays into tau lepton pair. In this talk, studies aiming to improve the separation power of the neural network between these processes will be presented.

T 70.3 Thu 17:00 H-HS I

**Track and SecondaryVertex Reconstruction of Tau Leptons in ATLAS** — •Kevin Bass, Peter Wagner, Michael Huebner, Klaus Desch, and Philip Bechtle — Universitaet Bonn

The Higgs boson decay into two tau leptons offers a unique way to test the Standard Model. Techniques to better characterize this decay in data collected from LHC runs are being improved. The Missing Mass Calculator (MMC) is used to estimate the di-tau mass and is an important discriminator between signal and background processes. I will introduce the concepts behind tau vertex reconstruction both in regards to and independently of the MMC and show how it can help to improve the predicted Higgs boson mass.

T 70.4 Thu 17:15 H-HS I

**Standard Model H→ $\tau\tau$ analysis with a neural network trained on a mix of simulation and data samples** — Günter Quast, •Moritz Scham, and Roger Wolf — Karlsruhe Institut für Technologie, Karslruhe, Deutschland

At the LHC, best access to the coupling of the observed Higgs boson to fermions is provided by the decay into $\tau$ leptons. For the measurement of simplified template cross sections in this decay channel CMS uses a multi-classification neural network to distinguish signal from background classes. In this talk a training of the neural network is presented, where the most important backgrounds from genuine di-$\tau$ events and from jets misidentified as $\tau$ leptons are obtained from data. In this way up to 90% of the background events are estimated from data, independent from the simulation.

T 70.5 Thu 17:30 H-HS I

**Measurement of the Higgs boson coupling to $\tau$ leptons using a multi-class neural network** — •Frank Sauerburger, Spyridon Argyropoulos, Shigeki Hirose, Karsten Koeneke, and Christian Weiser — Albert-Ludwigs-Universität Freiburg, Freiburg, Deutschland

A multivariate analysis using a multi-class neural network to measure the standard model coupling of the Higgs boson to $\tau$ leptons ($H \to \tau\tau$) is presented. The analysis focuses on the signal region enriched in vector-boson fusion (VBF) events. The background is estimated with a combination of Monte Carlo simulation and data-driven methods. A neural network is trained on multiple event categories of the background and signal model and employed to select VBF-like events. The rejection of background events and signal events originating from the gluon-fusion Higgs production mechanism increases the sensitivity of the analysis by increasing the signal to background ratio and reducing the systematic uncertainties of the theoretical prediction. The analysis is performed using the full Run 2 dataset of proton-proton collisions at a center-of-mass energy $\sqrt{s} = 13\,\text{TeV}$ corresponding to an integrated luminosity of $139\,\text{fb}^{-1}$ recorded with ATLAS detector at the LHC between 2015 and 2018.

T 70.6 Thu 17:45 H-HS I

**CP Violation in Higgs Boson Decays into two Tau Leptons with the CMS Experiment** — Mate Farkas, Olena Hlushchenko, Wolfgang Lohmann, Dennis Roy, Hale Sert, Sebastian Siebert, Achim Stahl, Lucas Wiens, and •Alexander Zotz — III. Physikalisches Institut B, RWTH Aachen University, Germany

Ever since the observation of the Higgs boson decay into a pair of tau leptons in 2016 by ATLAS and CMS, measurements of the structure of fermionic couplings have been made possible. Many of the Higgs boson's quantum numbers have been determined already, yet the full picture of its CP nature is unclear. The angle between the decay planes of the tau lepton decay products in the $H \to \tau\tau$ decay is a suitable observable to differentiate between different CP hypotheses including an admixture of odd and even states giving rise to CP violation.

In this talk, an analysis is presented to measure a CP mixing angle in fermionic Higgs boson decays via two tau leptons with the CMS experiment and in addition an estimation of the expected sensitivity for the data of Run 2 of the LHC is given.

T 70.7 Thu 18:00 H-HS I

**Making a Higgs to tau leptons coupling analysis at ATLAS: Behind the Scenes** — •Michael Hübner, Philip Bechtle, Klaus Desch, Christian Grefe, Lara Schildgen, and Peter Wagner — Universität Bonn

What are necessary ingredients to an analysis at ATLAS? Taking the previous instalment of the measurement of the $H \to \tau\tau$ rate from ATLAS [https://arxiv.org/abs/1811.08856], a very complex analysis can be described on only 29 pages. The experimental uncertainties are presented in less than one page. But what needs to happen behind the scenes to derive all these results?

This talk will cover some key aspects of the $H \to \tau\tau$ measurement that require a lot of work but which are not obvious at first glance:
How is the key observable for this analysis defined and what has to be done to use it?
How to estimate experimental uncertainties and how to improve those estimates?
What kind of technical infrastructure and code frameworks are needed to arrive at the final result?

T 70.8 Thu 18:15 H-HS I

**Analysis of CMS $\tau\tau$ events in SM and BSM interpretations** — •Artur Gottmann, Günter Quast, and Roger Wolf — Karlsruhe Institute of Technology, Wolfgang-Gaede-Str. 1, 76131 Karlsruhe, Germany

In the past, $\tau\tau$ analyses distinguished between the measurement of the

properties of the observed Higgs boson at 125 GeV and the search for additional heavy resonances from theories beyond the Standard Model (BSM).
Analyses of the observed Higgs boson were optimized on its kinematic properties from gluon fusion and vector boson fusion production with a sophisticated event categorisation, whereas the BSM searches were based on more inclusive event selections optimized for heavy resonances from gluon fusion and b-associated production.
However, a BSM motivated analysis of $\tau\tau$ events in predefined benchmark scenarios can profit from a comprehensive measurement that consistently includes all possible constraints from the observed Higgs boson and the search for additional heavy resonances. In this talk, such an approach will be proposed for future BSM interpretations of $\tau\tau$ analyses.

T 70.9 Thu 18:30 H-HS I

**Standard model Higgs physics in the $\tau\tau$ final state** — Janek Bechtel, Sebastian Brommer, Maximilian Burkart, Artur Gottmann, Simon Jörger, Günter Quast, Moritz Scham, Roger Wolf, Stefan Wunsch, and •Sebastian Wozniewski — Karlsruhe Institute of Technology, Karlsruhe, Germany

The $\tau\tau$ final state allows for highly relevant investigations of the Higgs sector in the context of couplings to fermions. With the data of the full LHC Run II, the sensitivity in this channel is large enough to aim for fiducial cross sections that are differential in the phase space of the Higgs boson production, known as simplified template cross section (STXS) measurements. This talk summarizes recent milestones on the way to a Run II legacy analysis of CMS in the context of the SM Higgs boson in the named decay channel. The machine learning approach that was presented earlier in a preliminary result has been further developed and tailored to this STXS measurement. Tau embedding and the extrapolation of background with jets misidentified as hadronic taus are used for both the training and the statistical inference, which makes this analysis data driven to a large extent and less dependent on the simulation of the underlying physics or detector and beam conditions.

T 70.10 Thu 18:45 H-HS I

**Measurements of Simplified Template Cross Sections in the H$\to\tau\tau$ decay channel at the ATLAS experiment** — •Fabian Becherer, David Hohn, and Markus Schumacher — Albert-Ludwigs-Universität Freiburg

The measurement of Simplified Template Cross Sections (STXS) is a strategy to study the Higgs boson at the LHC. The measurements of the signal strength $\mu$ and coupling modifiers $\kappa$ used in Run 1 make use of assumptions, such as the Standard Model kinematics or extrapolating from the measured phase space to the global phase space. These assumptions introduce theoretical uncertainties on the determined results and dependencies on the underlying physics model.
The STXS technique allows the reduction of theory dependencies in a systematic way, which are directly folded into the measurements. It provides more finely-grained measurements of cross sections in well-defined phase space regions. These measurements will benefit from the global combination of the measurements in all decay channels and the higher cross section for the Higgs boson production at $\sqrt{s}$=13 TeV in Run 2. Furthermore, the common definition used by the ATLAS and CMS experiments will allow a combination across them.
This talk will focus on the optimization of the H$\to\tau\tau$ decay channel analysis strategy of the ATLAS experiment for the full Run 2 data set. These measurements form an important input to combined STXS results, in particular for vector boson fusion and high transverse momentum topologies.