# Final Report

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| **Funding Programme:** | Helmholtz Young Investigators Groups |
| **Project ID No.:** | VH-NG-1004 |
| **Project Title:** | Ultimate precision measurements and searches for new physics using top quarks at the CMS experiment at the LHC |
| **Group Leader:** | Dr. Maria Aldaya Martin |
| **Helmholtz Centre:** | DESY |
| **Participating University:** | Karlsruhe Institute of Technology (KIT, University Sector), Hamburg |
| **Report Period:** | 04/2014 - 03/2017 |

## 1) Summary (max. 1 DIN A4 page)

*Please describe the main results and the progress achieved in comparison to the state of the art at the time of writing the application and give an outlook on possible future work and applications.*

The main achievements of the project encompass precision measurements of top quark pair (tt) production at the CMS experiment and the LHC, the measurement of tt production in association with a Higgs boson (tt+H) and its main background processes at CMS, and the investigation and participation in novel design options for the next CMS tracking detector. The results achieved are of high relevance for the physics program at the LHC, as they represent a major step forward in our understanding on the Standard Model (SM). Several measurements in the project are novel and have not been performed before.

In the SM, elementary particles acquire mass through their couplings to the Higgs boson (Higgs mechanism). The top quark, being the heaviest fundamental particle known to-date, is expected to be key to understanding this mechanism. The tt+H process is a direct probe of the top–Higgs Yukawa coupling and, thus, crucial to verify the SM nature of the Higgs boson. Moreover, many models of physics phenomena beyond the SM (BSM) expect the top quark to couple to yet unknown particles whose existence could hereby be revealed. Thus, it is essential to measure the properties of the top quark as precisely as possible and to investigate its interaction with the Higgs boson.
The YIG played a leading role in the first search for tt+H production in Higgs boson final states with two b quark jets (H->bb) at CMS at a centre-of-mass energy of 13 TeV.
This result has contributed to the first observation of the tt+H process, which was achieved by the combination of results from various production and decay channels of the Higgs boson. This establishes the direct coupling of the Higgs boson to the top quark, a vital missing piece in understanding the Higgs mechanism. Moreover, the tt+H(->bb) analysis also contributed to the first observation of the Higgs boson decaying into b quarks (H->bb) in CMS, achieved by the combination of H->bb results in different Higgs boson production modes. These observations mark an important milestone at the LHC.

The YIG performed high precision measurements of top quark properties at CMS at 8 and 13 TeV. Particular focus was set on differential tt production cross sections as a function of kinematic properties of the process in search for novel physics phenomena. The YIG has provided both the most precise results from the LHC Run1 and the very first results at 13 TeV on tt inclusive and differential cross sections. The results challenged and motivated the current state-of-the-art SM theoretical calculations, and were used to improve the simulations used in CMS in Run2. The measurements were also used to constrain SM

parameters and, for the first time, BSM physics in an Effective Field Theory approach. The group also pioneered measurements tt+bb and tt+jets, fundamental to understand the main background processes to tt+H(->bb) and to pave the way to the measurement of the Higgs boson couplings to top and b quarks.
Ultimate measurement precision for stringent tests of the SM will be achieved through the combination of results of the ATLAS and CMS experiments at the LHC. The YIG performed the first tt inclusive cross section combination at 8 TeV and established the path for the combination of tt differential cross sections to provide the LHC legacy Run1 result, as well as the basis for future combinations.

Since the start of the LHC in 2009, the CMS experiment has been operated very successfully. Particularly, the excellent performance of the CMS tracking system is an essential prerequisite for the successful continuation of top-quark-related measurements. With the LHC luminosity upgrade planned for 2023 (High-Luminosity LHC, HL-LHC), the current tracking system will have reached the end of its operational life span, and a new enhanced system must be built which can withstand the aggravated environment. The YIG contributed to the development of design options for tracker sensor modules. In particular, the group initiated and led the development of a novel working setup for high-precision automated assembly of the detector modules, including the design and test of the necessary glueing procedures. First prototype assemblies were successfully performed and presented to CMS.

## *2)* Work and Results Report

### a) Starting point (max. 1 DIN A4 page)

*Please describe the point(s) at issue, the aims and the working hypotheses of the project.*

At the time of the start of the YIG in 2014, the CERN LHC had just finished the Run1 data-taking period (comprising data collected in proton-proton collisions at centre-of-mass energies of 7 and 8 TeV) and was focused on the necessary preparations for Run2 at 13 TeV (2015-2018). The LHC was already established as a top quark factory and first measurements of its properties were performed. The top quark plays a very special role in the description of the structure and interactions. Being the heaviest fundamental particle, it offers a unique possibility to study bare quark properties and investigate Higgs couplings, and is expected to play an important role in various scenarios of new physics beyond the well established Standard Model. Thus, it is of great importance to measure the properties of the top quark as precisely as possible and to investigate its interaction with the Higgs.

Since the discovery of the Higgs boson at the LHC in 2012, the study of its properties became a major research target to verify if the new particle corresponds to the boson predicted by the SM. The measurements performed so far agreed with the SM expectations; however, the fermionic couplings of the new boson were among its least understood properties. In particular, a measurement of the top-Higgs Yukawa coupling was the crucial missing piece to ascertain the SM nature of the Higgs boson. The search at 13 TeV for top-quark-antiquark pair (tt) production in association with a Higgs boson (tt+H), a direct probe of the top–Higgs coupling, was the major goal of the proposal. Focus was set on final states where the Higgs boson decays into a b-quark-antiquark pair (H->bb), since it has precisely defined fermionic couplings in both production (top quarks) and decay (b quarks).
In order to investigate the interaction of the top quark with the Higgs boson and to search for possible deviations from the SM expectations, very precise knowledge of the top-quark properties was a key requisite. Further objectives of the proposal were high-precision measurements of tt production cross sections at 8 and 13 TeV as as a function of kinematic properties of the process in search for novel physics phenomena. Such measurements were not feasible before to the desired accuracy.
Measurements of tt+jets and tt+bb production (the latter never studied before) essential to pave the way to the observation of tt+H production and to the measurement of the Higgs

boson couplings to top and b quarks, were also planned. Ultimate measurement precision for stringent tests of the SM through the combination of results of the ATLAS and CMS experiments at the LHC was envisaged.

With the LHC luminosity upgrade planned for 2023 (High-Luminosity LHC, HL-LHC), the CMS tracking detector, in operation since 2009, was foreseen to be replaced by an enhanced one that is able to withstand the harsh radiation environment and ensure excellent performance for physics measurements in the future. This called for the development of completely new design concepts for tracker sensor modules that meet the demanding requirements in terms of mechanical stability, lightweight construction and the ability to guarantee highly efficient cooling for the silicon sensors to protect them from radiation damage. The proposal also targeted the investigation and participation in novel designs for tracker sensor modules.

**b) Description of the results (max. 4 DIN A4 pages)**

*Please describe the scientific and/or technical success of the group as well as secondary results achieved and essential experience gained. Please classify your own work within the national and international context.*

The topics addressed in the project are: precision measurements of top quark pair (tt) production at CMS and the LHC, the measurement of tt production in association with a Higgs boson (tt+H) and its main background processes at CMS, and the investigation and participation in novel design options for the HL-LHC CMS tracking detector. In the following, the activities of the group in these topics are summarized. The experimental analyses are performed within the international collaboration CMS at the LHC (in some cases, also within the ATLAS Collaboration).

**Precision measurements of inclusive and differential tt production at CMS and combination of results from the CMS and ATLAS Collaborations**

In order to investigate the interaction of the top quark with the Higgs boson and to search for possible deviations from the SM expectations, precise knowledge of the top-quark properties is a key requisite. Experimentally, SM top quark processes are also a dominant background to many searches for BSM physics. The YIG has focused on measurements of the tt production cross section, both inclusively and differentially as a function of tt kinematic observables. Through comparison with the state-of-the-art QCD predictions within the SM, the results allow for constraining SM parameters (e.g, top-quark mass, strong coupling constant), parton distribution functions (PDF), and improving tt Monte Carlo (MC) predictions. In addition, since the top quark plays a relevant role in BSM theories, such differential measurements are expected to be sensitive to new physics phenomena, as far as deviations of the top-quark properties from the SM expectation is concerned.

The highest precision can be obtained through the combination of results from CMS and ATLAS. Such combinations are important to provide the experimental and theory communities with highly precise and unified results from the LHC that have increased sensitivity to new physics phenomena and can be used to further constrain SM parameters. Inherent differences in the definition of physics objects and the determination of systematic uncertainties and their correlations across the experiments, as well as the requirement for a sound, transparent and well documented statistical treatment of all involved quantities, make the calculation of combined results a challenging endeavour.

*First tt cross section combination of ATLAS and CMS results at 8 TeV*

The YIG accomplished the first combination of inclusive tt production cross section results from the CMS and ATLAS collaborations at 8 TeV. The combined tt cross section resulted in an improvement of 11% in the accuracy of the measurement with respect to the most precise single-experiment result, and became the most precise cross section measurement of the Run1 of the LHC at that time.

*LHC Run1 legacy: Most precise tt inclusive cross section measurements at 7 and 8 TeV in CMS*

In close collaboration with the DESY group and groups from Spain and France, the YIG published a measurement of the inclusive tt production cross section at 7 TeV and 8 TeV using the full Run1 set of data. The tt production is identified via top-quark decays with an electron and a muon in the final state. The cross sections are measured using statistical methods that allow constraining in situ the most relevant sources of systematic uncertainties. With this analysis strategy, the tt cross section is measured with a precision of 3.6% at 7 TeV and 3.7% at 8 TeV, challenging the state-of-the-art of theoretical precision and resulting in the most precise measurement of its kind by CMS in Run1.

*First measurement of the tt cross section at 13 TeV using early 2015 data in CMS*

The YIG, together with the DESY group in collaboration with institutes from Spain, Belgium, US, and France, published the first measurement of the inclusive tt cross section at CMS with the first data collected in June 2015 at 13 TeV. A robust analysis technique based on counting of tt events is chosen over more involved methods to calculate the cross section at that early stage of the understanding of the CMS detector at the new energy regime.

*LHC Run1 legacy: Most precise tt differential cross section measurements at 8 TeV in CMS*

In collaboration with the DESY and the U. Hamburg groups, the YIG published a measurement of the tt differential production cross sections at 8 TeV. The measurement is performed in tt final states with up to two leptons. The cross sections are determined as a function of the kinematic properties of leptons, jets, top quarks or antiquarks, and the tt system. The results are compared to different SM predictions, finding overall good agreement with SM. However, the measured top quark transverse momentum ($p_T$(top)) was found to be lower than the predictions up to Next-to-Leading-Order (NLO) accuracy in QCD, but better described by a prediction beyond NLO; the tail of the invariant mass of the tt system (m(tt)) was also not well described by the predictions.
These observations were confirmed 2 years later by the ATLAS Collaboration. The measurements constitute the most precise results from the LHC Run1 on tt differential cross sections in CMS. A subset of these distributions were incorporated to PDF sets (e.g, NNPDF3.1).

*Determination of the top-quark mass from the tt+1jet distribution at 8 TeV in CMS*

The YIG, together with a PhD student from the DESY group, performed the determination of the top-quark mass from the normalized differential cross section as a function of the invariant mass of the tt system and the highest-$p_T$ additional jet (tt+1jet). The top-quark mass is extracted by comparing the measured tt +1jet differential cross section to NLO predictions. This way, the top-quark mass is determined in a well-defined theoretical scheme as used in perturbative QCD calculations (e.g pole mass), as opposed to the (most precise) direct measurements that rely heavily on less-well defined top-quark masses from MC simulations. The extracted top-quark mass is in agreement with other top-quark pole mass results and with the more precise direct top-quark mass measurements.

*Towards the first combination of tt differential cross sections from ATLAS and CMS*

Within the LHCtopWG, the YIG led the effort from the CMS side on the first combination of normalized tt differential cross sections from ATLAS and CMS using 8 TeV data. This is fundamental to provide theorists the final and unified word from the LHC Run1 on tt differential cross sections, as well as the proper inter-experiment correlations of the input measurements. Both the observables to combine and the corresponding binning of the data were agreed on. The proper mapping between the systematic uncertainties in the ATLAS and CMS measurements has been determined. A preliminary assessment of the correlation of the different sources of systematic uncertainties among the different bins of a given observable and across experiments has been performed. First preliminary results show a promising improvement in precision. This work is continued by the YIG leader beyond the end project.

D*ifferential tt cross sections, charge asymmetries & EFT constraints at 13 TeV in CMS*
The YIG has published a comprehensive set of absolute and normalized differential tt production cross section in final states with two leptons, using the full set of data at 13 TeV collected in 2016. This work extends the scope of the YIG's previous result in terms of the type of observables to measure, cross section definitions (particle and parton level), and improved precision. The results are compared to various NLO MC simulations and state-of-the-art of theoretical calculations beyond NLO. While general agreement with the SM is found, not all MC predictions are able to describe well all measured observables. The $p_T$(top) distribution in data remains to be lower than the predictions, but better described by the recent NNLO (QCD) + NLO (EW) calculations. The measurements are also used to determine, for the first time at 13 TeV at the LHC, the tt and leptonic charge asymmetries, which are sensitive to BSM effects. In addition, the measurements are used for the first time ever to constrain the top quark chromomagnetic dipole moment in an Effective Field Theory framework at NLO in QCD, in close cooperation with theorists (G. Durieux, C. Zhang).

**Measurements of associated production of top quark pairs and jets (tt+jets, tt+bb) at CMS**

A sound analysis of the Higgs-boson production associated with top-quark pairs (tt+H), where the Higgs boson decays to a b-quark-antiquark pair (bb), must comprise proper understanding of the most important background processes, all of which involve tt events. At the LHC, about half of the tt events contain additional high $p_T$ jets that do not come from the tt system (tt+jets). The additional jets typically arise from initial-state QCD radiation, and their study provides rigorous tests of the validity and completeness of higher-order QCD calculations describing the processes leading to multijet events, as well as supplies essential information for the measurement of Higgs boson properties and for searches for BSM phenomena.

Good experimental knowledge of tt+jets production and tt production in association with a bb pair from gluon splitting (tt+bb) is essential to pave the way to the observation of tt+H production and to the measurement of the Higgs boson couplings to top and b quarks. In particular, tt+bb production constitutes an irreducible, non-resonant background for tt+H(->bb). Moreover, the state-of-the-art of QCD calculations for tt+bb production have significant uncertainties from missing higher-order terms, making direct experimental measurements of this process desirable.

*First measurement of tt+jets and tt+bb production at 8 TeV in CMS*
The YIG, in close collaboration with the DESY group, has published the measurement of the cross section for tt production with additional jet activity (tt+jets), including b quark jets (tt+b, tt+bb), in the dilepton channel at 8 TeV. The measurement is performed differentially as a function of the number of jets in the event and of the kinematic properties of the additional jets. For the first time at the LHC, the kinematic properties of additional high $p_T$ b jets produced in association with tt events are measured differentially. Members of the group also worked in close collaboration with theorists (M.V. Garzelli) to provide an NLO tt+bb calculation interfaced to parton shower for comparison with data. The precision of the measured tt+b and tt+bb differential cross sections is limited by the size of the 8 TeV dataset.

Currently, members of the YIG are working on the measurement of the tt+bb differential cross sections at 13 TeV using the full Run2 dataset, extending the scope of the YIG's previous result in terms of the type of observables to measure, cross section definitions (particle and parton level), and improved precision. An optimized use of machine-learning techniques in employed to improve the distinction of the b-jets not coming from tt events. In parallel, members of the group are producing together M.V. Garzelli) updated tt+bb NLO theoretical calculations for comparison with data.

**Associated top quark pair production with a Higgs boson (tt+H(->bb)) at CMS**

The associated production of a Higgs boson with a top-quark pair is the best direct probe of the top-Higgs Yukawa coupling with minimal model dependence, a vital element to verify the SM nature of the discovered Higgs boson. A measurement of the tt+H production cross section also has the potential to distinguish the SM Higgs boson mechanism from alternative mechanisms to generate fermion mass.

However, the small SM cross section (~0.5 pb at 13 TeV, a factor of about 2000 smaller than tt production) makes this a very difficult measurement. The observation of tt+H and the measurement of the coupling are, therefore, amongst the major goals of the physics programme for the LHC Run2. Particularly interesting is the tt+H process where the Higgs boson decays into a b-quark-antiquark pair (H->bb), since it has the largest branching fraction (for a 125 GeV Higgs boson) and precisely defined couplings in both production (top quarks) and decay (b quarks). However, it is affected by overwhelming background from tt+jets, and especially, irreducible background from tt+bb. At the same time, the relatively poor jet-energy resolution and the huge combinatorial uncertainty in the event reconstruction require the use of multivariate analysis methods to discriminate signal from background processes, where the signal cross section is be determined with a fit of the discriminant distributions to the data.

*First search tt+H(->bb) production at 13 TeV in CMS*
Together with the KIT group, and in collaboration with ~15 international institutes, the YIG published the first search for the associated production of a Higgs boson with a top quark pair (tt+H), in final states with up to 2 leptons and where the Higgs boson decays into a bb pair (H->bb), at 13 TeV using the data collected in 2016. In order to increase the sensitivity of the search, selected events are split into several categories with different expected signal and background rates. In each category, signal and background events are separated pioneering a multivariate approach that combines a matrix element method with machine learning techniques (e.g, boosted decision trees).
More data are needed to possibly claim an observation of the tt+H(->bb) process, and YIG members are working on analyzing the full Run2 dataset (publication in preparation).

*First observation of the tt+H process in CMS*
The above mentioned tt+H(->bb) analysis performed by the YIG contributed to the first ever observation of the tt+H process. The ATLAS and CMS experiments independently observe a significant excess in data over background which is compatible with the SM prediction of the tt+H signal, when the measurements of the different individual decay channels using full Run1 and Run2 (up to 2017) data are combined. In a statistical analysis, each experiment disfavours the background-only hypothesis by at least 5 standard deviations, thereby claiming observation of the tt+H production mode of the Higgs boson at the LHC. Moreover, the tt+H(->bb) analysis also contributed to the first observation of the Higgs boson decaying into b quarks (H->bb) in CMS (also reported independently by ATLAS), achieved by the combination of H->bb results in different Higgs boson production modes.
Within the precision of theses measurements, the prediction of the top-Higgs Yukawa coupling and the mechanism giving mass to fundamental particles is confirmed. Analysing more LHC data will allow ATLAS and CMS to improve the sensitivity and perform even stricter validation of the SM, where any deviation would hint of new phenomena.

**Investigation and participation in novel design options for the next CMS tracking detector**

Within the DESY CMS Tracker Upgrade group, the YIG has led the development of a novel automated assembly system of detector modules for the upgraded CMS tracker for the HL-LHC, planned to start in 2026. DESY, in collaboration with other institutions in Germany and abroad, is responsible for building one tracker end-cap. The upgraded CMS tracker will consist of detector modules providing particle momentum measurements at the hit-level,

which is crucial for the trigger performance in the challenging data-taking conditions of the HL-LHC. The momentum measurement is performed by correlating hits in two closely-spaced silicon sensors within the module. As a result, the relative alignment of the two sensors must not be worse than 40 microns. The YIG developed an automated module assembly system, together with an assembly procedure, that meets the precision constraints, while offering improvements in cost, speed, and required manual labour associated with the module production with respect to manual approaches. The system will be used to build approximately 1000 detector modules for the CMS outer tracker.

*Development of an automated module assembly of detector modules*
An assembly setup consisting of a motion stage, sensor handling vacuum tool, and high-resolution camera was designed and commissioned by the YIG to provide the desired automation. In addition, a software application was developed to integrate these tools. The software obtains images of module components and processes them with a dedicated pattern-recognition algorithm, also designed by the group. The algorithm precisely deduces the location of module components and assembles them to the required precision via control of the motion and handling systems.
In order to speed up significantly the module production process, the automated assembly must reduce the 24-hour glue curing time between assembly steps needed in manual approaches. During that time, the assembly platform would remain inoperable while holding the components tightly in place. The YIG developed a gluing procedure where extremely small amounts of a fast-curing epoxy glue is used in addition to the low-viscosity, radiation-hard glue needed for the large-area glue joints of the assembled module. Instead of the assembly platform, the epoxy provides fixation and thus makes the automated assembly readily available for the next module.

The feasibility and fundamental precision capabilities of the setup were presented at the CMS Tracker Upgrade community. First prototype assemblies, including support structures and electronics, were successfully performed. The U. Brown (US) expressed interest in commissioning the automated assembly setup at their institute, and the collaboration between Brown and DESY was established.

*Design and test of gluing procedures for automatic module assembly*
The YIG investigated a range of possible glues for both large-area and fast gluing application, as well as different geometrical layout options for bonding. The study focused on the following properties of the adhesives and layouts: curing time; glue layer thickness, profile and viscosity; required amount of fast glue; interaction/contamination of fast and large-area glues. Practicable candidates have been identified, resulting in a procedure that requires only 15 minutes of curing time between assembly steps. This yields the potential for dramatic improvements in module production speed.

*Development and commissioning of an automated plasma cleaner system*
The assembled modules will be integrated into the tracker via mounting on semi-circular, carbon fibre structures known as „Dees“. The usage of plasma cleaning of the Dees has been investigated in order to improve both adhesion between the module and the Dee and handling in this integration step. The YIG contributed to the design and commissioning of a motion stage and associated software permitting precise control of the commercial plasma cleaner.

**c) Outlook on future work, sustainability (max. 2 DIN A4 pages)**
*Did you encounter unexpected effects or questions during the funding period? Do you see the need for further research in this respect? Please describe planned activities to further develop this work, also if to be carried out elsewhere or in a different constellation*

During the running of the project and based on the achieved results, several additional and related studies were started, expanding significantly the physics programme of the original

proposal.

Within the CMS MC Generator group, the YIG has been key player in the implementation, for the first time in CMS, of the Herwig7 MC generator. This is a crucial step towards improving the understanding of the modelling systematic uncertainties that affect top-quark-related measurements both in CMS and more generally at the LHC.

Within the CMS Top Quark Physics Analysis Group, the YIG provided crucial contributions to the validation and tuning of the tt simulation samples produced with improved MC generators for Run2. Based to a large extent on the studies of the group, the choice of the tt MC simulation suite to be used with CMS data collected in 2015 was made. In addition, some of the tt differential cross sections published by the group have been used by the CMS Collaboration to improve the modelling of the tt MC simulation that was used in top-quark measurements of 2016 data.

Based on the tt+bb differential cross sections measurements performed in the project, the YIG has been responsible for improving, within the official CMS software, the definitions of jet origin identification to allow for better gluon-quark jet identification as well as improvement of jet origin identification based on hadrons. This is particularly relevant for the measurement of processes such as tt+bb and tt+H(->bb). The improved definitions are being used in the ongoing Run2 measurements in CMS. Moreover, a member of the YIG is strongly involved in studies to improve the modelling of the tt+bb process by merging an inclusive tt+jets prediction with a dedicated simulation of tt+bb, following the merging scheme proposed in the "Handbook of LHC Higgs Cross Sections: 4”. This is expected to provide well defined uncertainties from perturbative QCD calculations instead of deriving the uncertainties from model dependent parton shower parameter variation as it is currently done in CMS.

Members of the YIG started a collaboration with the theory group of the U. Hamburg (Prof. Dr. S. Moch) to work on improving the precision of tt+H differential cross section calculations. These calculations include the impact of the running of the top quark mass on observables, which are expected to decrease the uncertainty on the calculations. In addition, work is ongoing in collaboration with Alessandro Broggio (Technische Universität München) and Andrea Ferroglia (City Tech, New York) to compare the state-of-the-art tt+H calculations.

The YIG was actively involved in the determination of the electron and muon identification and isolation efficiencies, dilepton trigger efficiencies, and the corresponding data-to-MC correction factors. These ingredients are crucial input for the correct measurement of the tt and tt+H processes pursued in the project, and have been incorporated successfully to the publications by the group and are also used elsewhere in the CMS Collaboration.

A member of the YIG coordinated and developed, within the Top Quark Physics Analysis Group, the trigger strategy to be used in top-quark-related measurements of 2017 and 2018 data, as well as the corresponding performance studies. This work was essential to ensure the proper trigger rates that allowed performing top-quark measurements at CMS with the data-taking conditions for the different run periods.

By the end of 2018, the Run2 of the LHC delivered data corresponding to a total integrated luminosity of about 150 $fb^{-1}$ at 13 TeV. The large data samples are currently being analyzed and will be critical for BSM physics searches in all possible signatures. Further consolidation of the Higgs sector, in particular, with the observation and measurement of tt+H production, as well as more precise coupling and differential cross section measurements will be followed up with high priority by the ATLAS and CMS experiments.
So far, no evidence for BSM physics has been observed and credible extensions of the SM are under pressure from the null result of a large variety of searches. However, even if no clear discovery is made at the LHC or future facilities for particle physics, it might still be indirectly probed through precision measurements of the properties of the SM particles.

In this context, the top quark is believed to play a crucial role, due to the closeness of its mass to the electroweak scale. This motivates the continuation of the intense research program dedicated to high-precision top-quark physics.

The topics addressed in the YIG project, namely, the measurement of tt+H production and direct measurement of the top-Higgs coupling, as well as high-precision measurements of top-quark properties, are among the most important goals of the LHC physics programme throughout its whole running period, and also for future colliders.

Concerning the work on the upgraded CMS tracker for the HL-LHC, the members of the group will continue the effort of building functional module prototypes within the CMS Collaboration, and ultimately constructing and commissioning one of the CMS tracker end-caps at DESY.

With the foreseen increase in luminosity in the next decades and finally reaching the design energy of 14 TeV, the LHC is expected to deliver up to 300 $fb^{-1}$ of data by ~2023 before the HL-LHC upgrade, and about 3000 $fb^{-1}$ afterwards. The properties of the Higgs boson must be measured to the highest achievable precision, including the Higgs self-coupling, and the precision of top quark (and electroweak) measurements must continue to improve, both as a way to reduce the systematic uncertainty on Higgs boson measurements and as potential probes of subtle BSM physics effects. As an example, the top-Higgs coupling is expected to be measured with a precision of ~14% (~4%) with 300 $fb^{-1}$ (3000 $fb^{-1}$) of data. However, the experimental challenges will also increase: heavy particles, in particular top quarks or Higgs bosons, will be produced with higher boost such that the spatial separation between their decay products will be harder to be resolved ("fat jets") and leptons from top-quark decays will be less well isolated. Furthermore, the number of parasitic proton-proton interactions ("pileup") will continue to increase strongly. As a consequence, improved analysis methods, more refined b-quark identification techniques, and new trigger developments will be mandatory.

**d) Potential for application/exploitation (max. 2 DIN A4 pages)**

*How do you yourself assess the potential for application or exploitation of the results? Where do you see future possibilities? Please describe realized or planned measures for applying the results. Please also include information on patents, licences, co-operations with industry, etc.*

The physics results achieved in the scope of the project are of high relevance for the fundamental research in high-energy physics. The novel automated tracker module assembly system developed in the project could be further developed into a generic solution for precise mechanical assembly projects in a broad range of research contexts.

**3) Qualification of Junior Researchers (max. 2 DIN A4 pages)**

*Please describe the structure of the Young Investigators Group in the course of the funding period and the main achievements regarding personal qualifications (including your own): Bachelor, Master; Diploma degrees, conferring of doctorates, "Habilitations", appointments/ junior professorships, tenure track, awards, etc. Please also describe any particularities as well as your work-related plans after the end of the funding period.*

The YIG consists of the group leader and the following members:

Post-doctoral researchers:
- Dr. Carmen Diez Pardos (01.04.2014 – 31.12.2018)
- Dr. Johannes Hauk (01.12.2015 – 30.06.2017, on parental leave from 13.04.2016 to 12.11.2016)
- Dr. James Keaveney (15.01.2016 – 28.02.2019)
- Dr. Jasone Garay Garcia (01.09.2016 – 30.11.2016)

- Several DESY Fellows have joined the YIG (one from 11.2014 – 08.2016; two from 01.2016 – 01.2018, one since August 2017) to work on the tt+H analysis for 30% of their time

PhD students:
- Mr. Mykola Savitskyi (01.09.2014 – 31.07.2018, University of Hamburg)
- Mr. Andrej Saibel (started 15.02.2017, University of Hamburg)

The post-doctoral researchers in the group hold/have held leading positions in the physics analyses and tracker upgrade activities at CMS and LHC, and gained significant visibility in their field of research.

In the following, the **qualification of the post-doctoral researchers of the YIG** is presented (in alphabetical order):

After the positive evaluation in 2017, the group leader remains on the staff scientist position at DESY. The group leader holds the coordination position of the CMS Top Quark Physics Analysis Group (TOP PAG) since Sep 2017, responsible for the definition of goals and requirements, coordination and scientific evaluation of results and publications in the field of top quark physics within the CMS collaboration (about 100 scientists from all over the world). She is also the CMS coordinator for top-quark pair differential cross section combinations with ATLAS within the LHC Top Working Group. From Sep 2015 to Sep 2017, the group leader was coordinator of the CMS Top Quark Cross Sections subgroup. In addition, she is the leader of the CMS Top Physics group at DESY-Hamburg since Apr 2014. She is also member of the CMS Analysis Review Committee (editorial board), and reviewer for scientific journals such as Eur. Phys. Journal C (since 2014) and J. High Energy Phys. (since 2018).

Dr. Carmen Diez Pardos is an outstanding particle physicist who was coordinator of the CMS Top Quark Mass subgroup (Sep 2016 - Aug 2018), coordinator of the CMS Top-Higgs Forum discussions (Sep 2016 - Sep 2018), and coordinator of the ttHbb working group at CMS (Sep 2017 - Nov 2018). In addition, she was the contact person between the TOP PAG and the Trigger Studies Group (Apr 2016 - Nov 2018) and the Muon Physics Object Group (2014 - 2016). She was also a member of the CMS Analysis Review Committee (2015 - Dec 2018) and is a reviewer for Eur. Phys. Journal C (since 2016). Moreover, she was the coordinator of the working meetings of the CMS Top Physics group at DESY-Hamburg. In January 2019, Dr. Diez Pardos accepted a permanent scientist position at the physics department of the University of Siegen (Germany) and is now member of the ATLAS Collaboration.

Dr. Johannes Hauk is a highly qualified particle physicist who was the coordinator of the ttHbb working group at CMS (Sep 2015 - Jun 2017). After his contract within the YIG finalized, and due to family constraints, he had to leave academia.

Dr. James Keaveney is an outstanding particle physicist who led at DESY the development of automated module assembly and metrology system for the detector modules of the CMS tracker for HL-LHC (Feb 2016 - Feb 2019). Moreover, he was coordinator of the CMS Top Quark Cross Sections subgroup (Sep 2014 - Nov 2016) and member of the CMS Analysis Review Committee (2014 - Feb 2019). In March 2019, Dr. Keaveney accepted a faculty position at the physics department of the University of Cape Town (South Africa) and joined the ATLAS Collaboration.

Dr. Jasone Garay Garcia is a highly qualified particle physicist who played a leading role in CMS in the first search for the tt+H(->bb) process at 13 TeV. After her contract within the YIG finalized, she left academia and took a successful job in industry as a data scientist specialized in machine learning techniques.

The details of the **qualification of the PhD students** is given below:

Mr. Mykola Savitskyi accomplished successfully his PhD at the University of Hamburg (10.3204/PUBDB-2018-02408, DESY-THESIS-2018-020) with *magna cum laude* in June 2018. From the start of his PhD (despite being at an early stage in his professional career), he was asked to take the responsibilities of the contact person between the TOP PAG and the Monte Carlo Generator Group in CMS (2014 - 2016). In September 2018, Dr. Savitskyi accepted the offer of a post-doctoral position within the DESY Fellowship Programme.

Mr. Andrej Saibel is finalizing his PhD work with affiliation University of Hamburg. From Feb 2018 to Jan 2019 he was employed by the U. Hamburg ("II. Institut für Theoretische Physik") to work with Prof. Dr. Sven-Olaf Moch on differential cross section calculations for tt+H, in addition to his experimental analysis of CMS data. Moreover, Mr. Saibel was contact person between the Higgs Physics Analysis and the Monte Carlo Generator Groups in CMS (2017 - 2019).

**4) Public relations**
*By which means did you gain publicity (e.g. reporting in media, own website)?*

The group is well represented in the community by about 15 public presentations per year by the group members at international workshops, conferences, and public seminars.

**5) Networking**
*What co-operation and communication structures (centre/university if applicable) have been developed during the course of the funding? How satisfied are you with the co-operation with the Helmholtz-Centre / university?*

The YIG is well integrated in the High Energy Physics department of DESY, in particular the CMS group, and contributes significantly to the research program of the Centre. Close cooperation between the YIG and the corresponding working groups in the fields of top quark physics, Higgs physics, and CMS tracker upgrade — both at DESY and partner universities KIT and U. Hamburg — is well established and reflected in several common projects, analyses, and publications. Additional close cooperation with the theory department of the U. Hamburg ("II. Institut für Theoretische Physik") has been established through a shared PhD student (A. Saibel).
DESY offers the perfect infrastructure for international research. The support of the Centre and the partner universities corresponds to the cooperation contract.

**Responsibilities of the YIG members within DESY and partner universities** (alphabetically ordered):

<u>Dr. M. Aldaya</u>

- Since 2015 — Leader of the DESY CMS subgroup CMS-F (composed of CMS-F1, CMS-F2, CMS-F3), in which the CMS Top Quark Physics research activity at DESY is carried out. The YIG is part of CMS-F1.
- 2016, 2017 — Lecturer at the Summer Semester Master Programme: "Teilchenphysik II – W, Z, Top am Collider" at U. Karlsruhe (15 lecturing hours/semester).
- 2016 - 2017 — Elected member of the DESY Scientific Committee (WA).
- Since 2014 — Convenor of the DESY-CMS Top Quark Physics Group at DESY Hamburg (about 20 scientists, including all YIG members), initiating and coordinating the analyses carried out by the group, and guiding the work of the PhD students and post-doctoral researchers.

Dr. C. Diez Pardos
- 2014 - Dec 2018 Coordinator of the working meetings of the DESY-CMS Top Quark Physics Group at DESY Hamburg.

Dr. J. Hauk
- 2016 - 2017 Coordinator of the working meetings of the DESY-KIT ttH analysis group. After he left, the role was taken over by a DESY Fellow associated with the YIG (M. Missiroli).

Dr. J. Keaveney
- 2016 - Feb 2019 Leader at DESY of the development of automated module assembly and metrology system for the detector modules of the CMS tracker for HL-LHC.

## 6) List of Publications

*Articles in scientific journals, written contributions to scientific meetings, contributions to books, other publications.*

**Major journal publications (in reversed chronological order):**

- CMS Collaboration, *Search for ttH production in the H->bb decay channel with leptonic tt decays in proton-proton collisions at 13 TeV,* J. High Energy Phys. 03 (2019) 026, arXiv: 1804.03682 [hep-ex]
- CMS Collaboration, *Measurements of ttbar differential cross sections in proton-proton collisions at sqrt(s) = 13 TeV using events containing two leptons*, J. High Energy Phys. 02 (2019) 149, arXiv:1811.06625 [hep-ex]
- CMS Collaboration, *Observation of Higgs boson decay to bottom quarks,* Phys. Rev. Lett. 121 (2018) 121801, arXiv:1808.08242 [hep-ex]
- CMS Collaboration, *Observation of ttH production,* Phys. Rev. Lett. 120 (2018) 231801, arXiv:1804.02610 [hep-ex]
- CMS Collaboration, *Measurement of normalized differential tt cross sections in the dilepton channel from pp collisions at sqrt(s) = 13 TeV*, J. High Energy Phys. 04 (2018) 060, arXiv:1708.07638 [hep-ex]
- CMS Collaboration, M*easurement of the inclusive tt cross section in pp collisions at sqrt(s) = 5.02 TeV using final states with at least one lepton*, J. High Energy Phys. 03 (2018) 115, arXiv:1711.03143 [hep-ex]
- CMS Collaboration, *Search for standard model production of four top quarks with same-sign and multilepton final states in proton-proton collisions at sqrt(s) = 13 TeV,* Eur. Phys. J. C 78 (2018) 140, arXiv:1710.10614 [hep-ex]
- CMS Collaboration, Combination of inclusive and differential tt charge asymmetry measurements using ATLAS and CMS data at *sqrt(s) = 7 and 8 TeV,* J. High Energy Phys. 04 (2018) 033, arXiv:1709.05327 [hep-ex]
- CMS Collaboration, *Search for standard model production of four top quarks in proton-proton collisions at sqrt(s) = 13 TeV,* submitted to Phys. Lett. B 772 (2017) 336, arXiv: 1702.06164 [hep-ex]
- CMS Collaboration, *Measurement of the tt production cross section in the eμ channel in pp collisions at sqrt(s) = 7 and 8 TeV,* J. High Energy Phys. 08 (2016) 029, arXiv: 1603.02303 [hep-ex]
- CMS Collaboration, *Measurement of the top quark pair production cross section in proton-proton collisions at sqrt(s) = 13 TeV*, Phys. Rev. Lett. 116 (2016) 052002, arXiv: 1510.05302 [hep-ex]
- CMS Collaboration, *Measurement of ttbar production with additional jet activity, including b quark jets, in the dilepton decay channel using pp collisions at sqrt(s) = 8 TeV,* Eur. Phys. J. C 76 (2016) 379, arXiv:1510.03072 [hep-ex]
- CMS Collaboration, *Measurement of the differential top quark pair production cross section in pp collisions at sqrt(s) = 8 TeV*, Eur. Phys. J. C 75 (2015) 542, arXiv: 1505.04480 [hep-ex]

- CMS Collaboration, *Measurement of jet multiplicity distributions in tt production in pp collisions at sqrt(s) = 7 TeV*, Eur. Phys. J. C74 (2014) 3014, arXiv:1404.3171 [hep-ex]
- CMS Collaboration, *Search for the associated production of the Higgs boson with a top-quark pair*, J. High Energy Phys. 09 (2014) 087, arXiv:1408.1682 [hep-ex]

As coordinator of the CMS Top Quark Physics Group since Sep 2017, the YIG leader is directly responsible (co-editor, internal referee) for 15 additional journal publications (http://cms-results.web.cern.ch/cms-results/public-results/publications/TOP/index.html), among which are:

- CMS Collaboration, *Measurement of ttbar normalised multi-differential cross sections in pp collisions at sqrt(s) = 13 TeV, and simultaneous determination of the strong coupling strength, top quark pole mass, and parton distribution functions*, arXiv:1904.05237 [hep-ex] (submitted to Eur. Phys. J. C)
- CMS Collaboration, *Observation of single top quark production in association with a Z boson in proton-proton collisions at sqrt(s) = 13 TeV,* Phys. Rev. Lett. 122 (2019) 132003, arXiv:1812.05900 [hep-ex]
- CMS Collaboration, *Measurement of ttbar production cross section, the top quark mass, and the strong coupling constant using dilepton events in pp collisions at sqrt(s) = 13 TeV,* Eur. Phys. J. C 79 (2019) 368, arXiv:1812.10505 [hep-ex]

**Major public preliminary results (in reversed chronological order):**
(NB: only results that are not superseded by the corresponding journal publication are included):

- CMS Collaboration, Measurements of the top quark polarization and ttbar spin correlations in dilepton final states at *sqrt(s) = 13 TeV*, CMS Physics Analysis Summary CMS-PAS TOP-18-006 (2019), journal publication in preparation
- CMS Collaboration, *Search for ttH production in the H->bb decay channel with 2016 pp collision data at sqrt(s) = 13 TeV*, CMS Physics Analysis Summary CMS-PAS HIG-16-038 (2016)
- CMS Collaboration, *Search for ttH production in the H->bb decay channel with sqrt(s) = 13 TeV pp collisions at the CMS experiment*, CMS Physics Analysis Summary CMS-PAS HIG-16-004 (2016)
- CMS Collaboration, *Measurement of the differential cross section for ttbar production in the dilepton final state at 13 TeV*, CMS Physics Analysis Summary CMS-PAS TOP-16-011 (2016)
- CMS Collaboration, *Determination of the normalized invariant mass distribution of tt+1jet and extraction of the top quark mass*, CMS Physics Analysis Summary CMS-PAS TOP-13-006 (2016)
- CMS Collaboration, *First measurement of the differential cross section for ttbar production in the dilepton final state at 13 TeV*, CMS Physics Analysis Summary CMS-PAS TOP-15-010 (2015)
- ATLAS and CMS Collaborations, *Combination of ATLAS and CMS top quark pair cross section measurements in the eμ final state using proton-proton collisions at sqrt(s) = 8 TeV*, CMS Physics Analysis Summary CMS-PAS TOP-14-016 (2014)

As coordinator of the CMS Top Quark Physics Group since Sep 2017, the YIG leader is directly responsible (co-editor, internal referee) for 7 additional public results (http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/TOP/index.html), among which are:

- CMS Collaboration, *Search for standard model production of four top quarks in final states with same-sign and multiple leptons in proton-proton collisions at sqrt(s) = 13 TeV,* CMS Physics Analysis Summary CMS-PAS TOP-18-003 (2019)

- CMS Collaboration, *Constraining the top quark Yukawa coupling from ttbar differential cross sections in the lepton+jets final state in proton-proton collisions at sqrt(s) = 13 TeV,* CMS Physics Analysis Summary CMS-PAS TOP-17-004 (2019)

**Public presentations by the group members (in reverse chronological order):**

- J. Keaveney, *Results on top quark physics from ATLAS, CMS and LHCb*, invited talk at Kruger2018: Discovery Physics at the LHC, Kruger National Park (South Africa), 3 – 7 Dec 2018
- J. Keaveney, *Recent* d*ifferential ttbar measurements in CMS*, parallel talk at Terascale18: Terascale Alliance Annual Meeting, DESY Hamburg (Germany), 26 – 28 Nov 2018
- A. Saibel, *Differential tt+bb cross section measurements at 13 TeV in leptonic final states,* invited plenary talk at CMS TOP Group Workshop 2018, CERN (Switzerland), 6 – 7 Nov 2018
- J. Keaveney, *CMS Highlights,* Report to the 86th Physics Research Committee, Zeuthen (Germany), 16 Oct 2018
- M. Aldaya, F. Canelli, *TOP PAG planning for full Run2*, plenary talk at CMS Week, Budapest (Hungary), 2 Oct 2018
- A. Saibel, *Search for ttH, H—>bb decays using the full 2016 data sample*, poster at TOP2018: 11th International Workshop on Top Quark Physics, Bad Neuenahr (Germany), 16 – 21 Sep 2018
- C. Diez Pardos, *Measurements of ttH production*, parallel talk at ICHEP2018: 39th International Conference on High Energy Physics, Seoul (Korea, Republic Of), 4 – 11 Jul 2018; proceedings: CMS CR-2018/346
- J. Keaveney, *Automated Silicon Module Assembly,* parallel talk at 4th Matter and Tecnhologies Annual Meeting, Berlin (Germany), 12 – 14 Jun 2018
- C. Diez Pardos, *Observation of Top Quark Pair Production in Association with a Higgs Boson*, seminar at DESY, Hamburg and Zeuthen (Germany), 5 – 6 Jun 2018
- C. Diez Pardos, *Recent ttH/tH results from CMS*, plenary talk at Benasque-Higgs2018: Higgs Toppings Workshop - Probing Top-Higgs Interactions at the LHC, Benasque (Spain), 27 May – 2 Jun 2018
- J. Keaveney, *Searches for new physics in the higgs, top and electroweak sector,* plenary talk at Alps2018: Third Alpine LHC Physics Summit, Obergurgl (Austria), 15 – 20 Apr 2018
- C. Diez Pardos, *Top Quark Physics at the LHC*, invited talk (Hauptvortrag) at DPG2018: Frühjahrstagung der Deutschen Physikalischen Gesellschaft - Teilchenphysik, Würzburg (Germany), 19 – 23 Mar 2018
- A. Saibel, *Differential cross section measurement of top quark pair production with associated bottom quarks in the dilepton channel at 13 TeV*, parallel talk at DPG2018: Frühjahrstagung der Deutschen Physikalischen Gesellschaft - Teilchenphysik, Würzburg (Germany), 19 – 23 Mar 2018

- C. Diez Pardos, *Trigger report*, invited talk at Top! Hammertime (a CMS top quark workshop), CERN (Switzerland), 14 – 15 Nov 2017
- J. Keaveney, *Recommendations on the calibration of the top pt spectrum*, invited talk at Top! Hammertime (a CMS top quark workshop), CERN (Switzerland), 14 – 15 Nov 2017
- M. Aldaya, R. Gonzalez Suarez, *TOP PAG plans*, plenary talk at CMS Physics Planning meeting, CERN (Switzerland), 26 Oct 2017
- J. Keaveney, *The automated module assembly of stacked detector modules*, poster at VERTEX2017, Asturias (Spain), 10 – 16 Sep 2017
- J. Keaveney, T*op pt measurements at the LHC*, invited talk at Heavy Flavour Production at the LHC, Durham (UK), 6 – 8 Sep 2017
- C. Diez Pardos, *Top quark physics in ATLAS and CMS*, plenary talk at Corfu2017: Workshop on the Standard Model and Beyond, 2 – 10 Sep 2017
- M. Aldaya, *Top quarks at the new energy frontier*, invited seminars at DESY Hamburg and Zeuthen (Germany), 23 – 24 May 2017

- C. Diez Pardos, *Top quark mass measurements with the CMS experiment*, invited seminar at U. Rome, Tor Vergata, (Italy), 27 April 2017
- A. Saibel, *Studies of tt+jets Monte Carlo simulations for the ttH, H->bb analysis at CMS,* parallel talk at DPG-Frühjahrstagung Münster (Germany), 27 – 31 Mar 2017
- M. Savitskyi, *Measurement of the differential cross section for top-quark-pair production in the dilepton channel at 13 TeV with the CMS detector,* parallel talk at DPG-Frühjahrstagung Münster (Germany), 27 – 31 Mar 2017
- J. Keaveney, *Automated precision assembly of stacked sensor modules*, parallel talk at Annual Meeting of the Helmholtz Programme "Matter and Technologies", GSI Darmstadt (Germany), 31 Jan – 2 Feb 2017

- M. Aldaya et al., *Top Quark Physics at the LHC*, poster at MUTAG2016: 2nd Annual Symposium of the Helmholtz Programme Matter and the Universe, Helmholtz Institute Mainz (Germany), 12 – 13 Dec 2016
- K. el Morabit et al., *Recent CMS results on the search for ttH production*, parallel talk at 10th Annual Meeting of the Helmholtz Alliance „Physics at the Terascale", DESY Hamburg (Germany), 21 – 23 Nov 2016
- C. Diez Pardos et al., *Top mass with 100 fb$^{-1}$,* talk at the CMS workshop: Top @ 100 fb$^{-1}$, CERN Geneva (Switzerland), 8 – 9 Nov 2016
- J. Keaveney, *New $\sigma_{tt}$ analyses,* talk at the CMS workshop: Top @ 100 fb$^{-1}$, CERN Geneva (Switzerland), 8 – 9 Nov 2016
- M. Aldaya, et al., *Top quark pair cross section measurements @ 100 fb$^{-1}$: introduction and context*, talk at the CMS workshop: Top @ 100 fb$^{-1}$, CERN Geneva (Switzerland), 8 – 9 Nov 2016
- C. Diez Pardos, *tt cross section measurements in CMS*, plenary talk at TOP2016: 9th International Workshop on Top Quark Physics, Olomouc (Czech Republic), 18 – 23 Sep 2016; proceedings: arXiv:1611.06524 [hep-ex]
- M. Savitskyi, *Measurement of the differential cross section for top-quark-pair production in the dilepton channel at 13 TeV with the CMS detector*, poster at TOP2016: 9th International Workshop on Top Quark Physics, Olomouc (Czech Republic), 18 – 23 Sep 2016; proceedings: arXiv:1611.09657 [hep-ex]
- J. Keaveney, *Top pair cross section measurements (incl./diff.) and event modelling with the CMS detector*, parallel talk at ICHEP 2016: 38th International Conference on High Energy Physics, Chicago (USA), 3 – 10 Aug 2016; proceedings: PoS(ICHEP2016)653
- M. Aldaya, *Recent results on top quark physics,* invited plenary talk at the 28th Rencontres de Blois on Particle Physics and Cosmology, Blois (France), 29 May – 3 Jun 2016
- M. Savitskyi, *Towards ultimate precision in dilepton channel (differential)*, invited talk at the CMS workshop: Towards ultimate precision on top cross sections with the 2016 dataset, CERN Geneva (Switzerland), 29 Apr 2016
- C. Diez Pardos, *Prospects for modeling of trigger, lepton ID and isolation efficiencies*, invited talk at the CMS workshop: Towards ultimate precision on top cross sections with the 2016 dataset, CERN Geneva (Switzerland), 29 Apr 2016
- J. Keaveney, M. Aldaya, *Introduction and top cross section prospects with 30 fb$^{-1}$*, opening talk at the CMS workshop: Towards ultimate precision on top cross sections with the 2016 dataset, CERN Geneva (Switzerland), 29 Apr 2016
- J. Hauk, *Results and prospects for ttH at CMS*, plenary talk at 51st Rencontres de Moriond EW 2016, La Thuile (Italy), 12 – 19 Mar 2016
- M. Savitskyi, *Measurement of the differential cross section for top-quark pair production in the dilepton channel at 13 TeV with the CMS detector*, parallel talk at DPG-Frühjahrstagung Hamburg (Germany), 29 Feb – 4 Mar 2016
- J. Hauk, *The Top Quark and the Higgs boson: Vital Actors at LHC*, invited talk at DPG-Frühjahrstagung Hamburg (Germany), 29 Feb – 4 Mar 2016

- C. Diez Pardos, *ATLAS and CMS inclusive top quark pair cross section measurements*, plenary talk at Open Meeting of the TOP LHC Working Group, CERN Geneva (Switzerland), 17 – 18 Nov 2015

- M. Aldaya, F. Spano, *ATLAS and CMS tt differential cross section measurements at sqrt(s) = 8 TeV*, plenary talk at Open Meeting of the TOP LHC Working Group, CERN Geneva (Switzerland), 17 – 18 Nov 2015
- J. Hauk, *Measurement of tt production with additional jet activity, including b quark jets, in the dilepton decay channel using pp collisions at sqrt(s) = 8 TeV*, parallel talk at 9th Annual Meeting of the Helmholtz Alliance „Physics at the Terascale“, DESY Hamburg (Germany), 17 – 18 Nov 2015
- C. Diez Pardos, *Top quark pair inclusive cross section in the emu channel at 7, 8, and 13 TeV with the CMS experiment*, parallel talk at 9th Annual Meeting of the Helmholtz Alliance „Physics at the Terascale“, DESY Hamburg (Germany), 17 – 18 Nov 2015
- M. Savitskyi, *Differential cross section for tt production at 8 and 13 TeV*, parallel talk at 9th Annual Meeting of the Helmholtz Alliance „Physics at the Terascale“, DESY Hamburg (Germany), 17 – 18 Nov 2015
- C. Diez Pardos, *13 TeV Forum: First Results from LHC Run-II*, plenary talk at DESY Physics Seminar, Hamburg and Zeuthen (Germany), 3-4 Nov 2015
- M. Aldaya, *Recent top quark physics results from CMS*, invited plenary talk at CMS FSP Workshop, KIT Karlsruhe (Germany), 7-9 Oct 2015
- M. Savitskyi, *First measurement of the differential cross section for tt production in the dilepton final state at sqrt(s) = 13 TeV*, parallel talk at CMS FSP Workshop, KIT Karlsruhe (Germany), 7-9 Oct 2015
- C. Diez Pardos, *Measurements of tt + X with the ATLAS and CMS Experiments*, parallel talk at LHCP2015: The Third Annual Large Hadron Collider Physics Conference, St. Petersburg (Russia) 31 Aug - 5 Sep 2015, Proceedings CMS CR-2015/356
- M. Aldaya, *Measuring the differential cross section for top quark pair production at 8 TeV*, poster at European Physical Society Conference on High Energy Physics 2015, Vienna (Austria), 22 – 29 Jul 2015
- M. Savitskyi, *First studies towards top-quark pair differential cross section measurement in the dilepton channel at sqrt(s) = 13 TeV with the CMS detector*, “new talents” talk at the International school of subnuclear physics 2015: 53rd course: the future of our physics including new frontier, Erice (Italy), 24 Jun – 3 Jul 2015
- C. Diez Pardos, *Status of CMS at DESY*, Report to the 79th Physics Research Committee, Hamburg (Germany), 11 May 2015
- M. Savitskyi, *First studies towards top-quark pair cross section measurement in the dilepton channel at 13 TeV with the CMS detector*, parallel talk at DPG-Frühjahrstagung Wuppertal (Germany), 9 - 13 Mar 2015
- C. Diez Pardos, *Measurements of Top Quark Pair Production with the CMS Experiment*, invited talk at DPG-Frühjahrstagung Wuppertal (Germany), 9 - 13 Mar 2015
- M. Aldaya, F. Spano, *ATLAS+CMS 8 TeV ttbar cross section combination and status and plans for differential distributions*, plenary talk at Open Meeting of the TOP LHC Working Group, CERN Geneva (Switzerland), 12 – 13 Jan 2015

- M. Aldaya, *Prospects for LHC top quark pair cross section combinations*, Open Meeting of the TOP LHC Working Group, CERN Geneva (Switzerland), 21 – 23 May 2014
- M. Aldaya, *Combination of top quark physics results at the LHC*, ICHEP2014: 37th International Conference on High Energy Physics, Valencia (Spain), 2 – 9 Jul 2014
- C. Diez Pardos, *Top production with N-jets and with jet vetoes,* JetLHC2014: Workshop on Jet Vetoes and Jet Multiplicity Observables at the LHC, IPPP, Durham (United Kingdom), 16-18 Jul 2014
- M. Aldaya, F. Spano, *Thoughts for discussion on experimental challenges and prospects*, invited talk at the Topical Workshop on Top quark Differential Distributions, Cannes (France), 26 – 28 Sep 2014

- C. Diez Pardos, *Latest results on differential cross sections at the LHC and Tevatron (measurements as a function of kinematics variables)*, TOP2014: 7th International Workshop on Top Quark Physics, Cannes (France), 29 Sep – 3 Oct 2014

In addition, YIG members have participated in the organization of: conferences (TOP2018, TOP2019 — M. Aldaya); workshops on top quarks (M. Aldaya, C. Diez Pardos and J. Keaveney), b-tagging (M. Aldaya), top and Higgs (M. Aldaya, C. Diez Pardos); schools and tutorials on data analysis at the LHC (C. Diez Pardos).

**Dissertations:**

M. Savitskyi, *Measurements of differential cross sections for tt production in proton-proton collisions at sqrt(s) = 13 TeV using events containing two leptons with the CMS experiment*, University of Hamburg, June 2018, PhD Thesis, DESY-THESIS-2018-020