

Annual Report

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 (=Calendar Year):	01/2014-12/2014

1) Group Structure

Please report briefly on the structure and personnel development of your group.

The group (start date: 01.04.15) consists of the group leader and the following members:

Post-doctoral researchers:

- Dr. Carmen Diez Pardos (started 01.04.2014)

PhD students:

- Mr. Mykola Savitskyi (started 01.09.2014, University of Hamburg)

2) Network

Please describe how you / your research group are integrated within the Helmholtz Centre and the partner university (e.g. as member of committees).

The Young Investigator Group (YIG) is integrated in the High Energy Physics department of DESY, in particular the CMS group, and contributes significantly to the research program of the Centre. As planned in the project, a 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 has been established.

Since May 2014, the YIG leader is the coordinator of the CMS Top Quark Physics group at DESY (composed, as of December 2014, of 5 staff scientists, 4 post-doctoral researchers, and 9 PhD students), initiating and coordinating the analyses carried out by the group, and guiding the work of the PhD students and post-doctoral researchers.

In addition, the YIG leader is an associated scientist in the Karlsruhe Research Training Group GRK 1694: *Elementarteilchenphysik bei höchster Energie und höchster Präzision* (Graduiertenkolleg) (renewal application under review process).

3) Satisfaction

How satisfied are you with the general working conditions provided by the Helmholtz Centre / partner university? Is there anything that meets your criticism?

DESY offers the perfect infrastructure for international research. The support of the Centre and the partner universities, in general, corresponds to the cooperation contract. However, the requirement from DESY to search for the postdoctoral staff for the YIG among the applicants to the DESY Fellowship Programme, makes it very difficult to find appropriate

candidates with the required expertise to fulfill the foreseen post-doctoral position on detector development.

4) Scientific Progress / Milestones

How has your work plan progressed? Which important milestones could be achieved during the report period? Is the progress of your work in accordance with original planning or has the work plan been changed?

The activities of the group are divided into several working packages that address the different topics described in the project: precision measurements of top quark pair ($t\bar{t}$) production at the LHC, the measurement of $t\bar{t}$ production in association with a Higgs boson ($t\bar{t}+H$) and its main background processes at CMS, and the investigation and participation in novel design options for the next CMS tracking detector. The work plan is progressing in accordance with the original planning.

In the following, the progress of each of the working packages is summarized.

Precision measurements of inclusive and differential top quark pair ($t\bar{t}$) production at CMS and combination of results from the CMS and ATLAS Collaborations

The group is playing a key role in the Top Quark Physics Analysis Group of the CMS experiment and works together with the DESY CMS Top Quark Physics group. In addition, the group is leading the combination of $t\bar{t}$ cross sections results of the CMS and ATLAS Collaborations at the LHC.

- The YIG has accomplished the first combination of inclusive $t\bar{t}$ production cross section results from the CMS and ATLAS Collaborations at a centre-of-mass energy $\sqrt{s} = 8$ TeV [1]. The combined $t\bar{t}$ cross section results in an improvement of 11% in the accuracy of the measurement with respect to the most precise single-experiment result, and it has become the current most precise cross section measurement of the Run-I of the LHC. The combination is found to be in good agreement with all individual measurements and with the state-of-the-art of the Standard Model (SM) predictions for $t\bar{t}$ production at full NNLO+NNLL accuracy. Furthermore, the group, within the Top LHC Working Group and together with a small group of experts from the ATLAS experiment, has provided the reference $t\bar{t}$ predictions to be used by the CMS and ATLAS Collaborations. These predictions are obtained using public software which implement the mentioned theoretical calculations, but provide a more suitable choice of parameters that meet the requirements from the experiments.
- In close collaboration with the DESY group and groups from IFCA (Spain), University of Oviedo (Spain) and IPHC (France), the YIG is working on the „Run-I legacy“ measurement of the inclusive $t\bar{t}$ production cross section at $\sqrt{s} = 7$ TeV and 8 TeV using the full Run-I dataset [2]. The $t\bar{t}$ production is identified via top quark decays with two leptons in the final state (so-called dilepton channel). The cross sections are measured using techniques that allow constraining in-situ the most relevant systematic uncertainties, leading to much improved precision with respect to the current existing CMS measurements. These results are expected to be the final word of the LHC Run-I on $t\bar{t}$ cross section measurements in the dilepton channel at CMS.
- The group has accomplished the measurement of the $t\bar{t}$ differential production cross sections at 8 TeV using the full Run-I dataset, which is currently in the final stages of the publication procedure [3]. The measurement is performed in the dilepton channels as well as in $t\bar{t}$ final states with one lepton ($l+\text{jets}$ channel). The cross sections are determined as a function of the kinematic properties of leptons, jets, top (antitop) quarks, and the $t\bar{t}$ system. The results are compared to different SM predictions and no deviations from the SM are observed. The measurement has been performed in collaboration with the DESY and the University of Hamburg groups, and constitutes the final word of the LHC Run-I on $t\bar{t}$

differential cross section measurements in the dilepton and l+jets channels at CMS.

- The work towards possible combination of tt differential cross section results from the CMS and ATLAS Collaborations has started. Within the Top LHC Working Group, the YIG is working on determining the compatibility of the differential cross section results from ATLAS and CMS, which is a necessary step towards possible combinations. The consistency of the definition of the top quark and tt system was confirmed by performing studies of the different Monte Carlo (MC) predictions used by both collaborations. An outcome of the studies of the group was the difference observed between the transverse momentum (p_T) of the top quark predicted by Powheg+Herwig and all other considered predictions, which is consistently observed by ATLAS and CMS. This difference, and the fact that this prediction describes CMS data better, has triggered studies by theoreticians (P. Nason et al.) to understand the effect, leading to ongoing discussions within the theory community (M. Mangano, A. Mitov, et al.).

Measurements of associated top quark pair production with a Higgs boson (tt+H(\rightarrow bb)) and its main background processes tt+jets, tt+bb at CMS

- The group, in close collaboration with the KIT group, has published the first measurement of jet multiplicity distributions in tt production at 7 TeV in the dilepton and l+jets channels in CMS [4]. The measurement of additional high p_T jets often produced in association with top quark pairs (tt+jets) are affording rigorous tests of perturbative quantum chromodynamics (QCD), as well as supplying essential information for the measurement of Higgs boson properties and for searches for phenomena beyond the SM. The data are compared to different SM predictions and are precise enough to exclude some of the models. This result is featured in the „DESY Highlights 2014“ brochure (in preparation).
- The YIG is working, in close collaboration with the DESY group, on the first CMS measurement of tt+jets and tt+bb in the dilepton channel at 8 TeV [5]. For the first time at the LHC, the kinematic properties of additional high p_T jets stemming from b quarks (b jets) produced in association with top quark pairs (tt+bb) are measured. Good experimental knowledge of these processes will pave the way to the observation of the Higgs boson in association with a top quark pair (tt+H) and to the measurement its couplings to top and b quarks. The analysis is well advanced and the journal publication is in preparation.
- The group is also working on the first determination of the top quark pole mass from the tt differential cross section as a function of the invariant mass of the tt system and one additional jet (tt+1jet) using 8 TeV data at CMS [6]. The top quark pole mass is extracted by comparing the measured tt +1jet differential cross section to different NLO predictions. This approach allows obtaining the top quark mass in an unambiguous definition, while the direct measurements typically rely heavily on less-well defined top quark masses from MC simulations. The analysis, which is performed together with a PhD student from the DESY group, is well advanced and a preliminary result is in preparation.
- The paper „Search for the associated production of the Higgs boson with a top quark pair“, to which the group has contributed by providing trigger efficiencies, lepton identification and isolation efficiencies, and data-to-MC correction factors, has been published [7].

Preparation for the first tt and tt+H measurements at CMS for the LHC Run-II

- The YIG is actively involved in all the necessary technical work in preparation for the LHC Run-II proton-proton collisions at 13 TeV (starting in June 2015). In particular, the group is participating in the official CMS software challenge and MC validation exercises „CSA14“ (Computing, Software and Analysis challenge) and „PHYS14“ (Physics analysis validation) for both the Top Quark Physics and the Higgs Physics Groups. The results are foreseen to

be presented at the relevant meetings in the CMS Collaboration in January 2015.

- The YIG has taken over the responsibility within the CMS Top Quark Physics Group to contribute to the validation of the $t\bar{t}$ MC samples that are being produced with new generators, both at 8 and 13 TeV. Based on this validation, the choice of the $t\bar{t}$ simulations to be used for physics analysis will be made.
- The group, together with the DESY group and in collaboration with U. Oviedo (Spain), U. Ghent (Brussels), IFCA (Spain), U. Riverside (US), and IPHC (France), is starting to work towards the „Early Analysis“ of the inclusive $t\bar{t}$ production cross section at CMS with the first data that will be collected in June 2015 at 13 TeV. The measurement will be performed using the dilepton final state, which is especially suited due to the low contamination from background processes. The result is expected to be published by August 2015.
- The group is also starting to work on the CMS „Early Analysis“ of the differential $t\bar{t}$ production cross section at 13 TeV in the electron-muon final state. The $t\bar{t}$ cross section will be measured as a function of the decay products of the $t\bar{t}$ system (leptons, jets, b-jets), of the top quarks themselves and of the $t\bar{t}$ system. The result is targeting at the TOP2015 conference in September 2015.
- In collaboration with 15 international institutes (in particular with DESY, KIT, Ohio State U. (US), U. Virginia (US), and U. Notre Dame (US)), the YIG is starting to set up the analysis framework to perform the $t\bar{t}+H$ analysis at 13 TeV using the full dataset of 2015. The $t\bar{t}$ production is identified via top quark decays with two leptons in the final state and the Higgs boson decays into a b quark pair. The analysis builds up from the $t\bar{t}$ analysis at 13 TeV.
- In the context of the $t\bar{t}$ inclusive and differential „Early Analysis“ and the $t\bar{t}+H$ analysis at 13 TeV, the group is also involved in the determination of the electron and muon identification and isolation efficiencies, the dilepton trigger efficiencies and the data-to-MC correction factors (so far determined using simulation). These ingredients will be crucial input for the correct measurement of these processes.

Investigation and participation in novel design options for the CMS tracker upgrade

- In close collaboration with the DESY Tracker Upgrade Group, the YIG is working on first studies for the characterization of high performance materials that are foreseen to be used in the support structures of the silicon modules of the upgraded CMS tracker for the High-Luminosity LHC. In particular, the group is investigating phase-change thermal interface materials as possible glue types for the different components of the support structure for the silicon modules, as well as feasible techniques for the application of the glue to the components of the silicon modules.
- First measurements on the glue layer quality have been performed by building sandwich test structure prototypes composed of those materials currently being focused on by the CMS upgrade collaboration for use in the next CMS tracker (C-Foam and AIREX). The microscopic analysis of thin sections of the test structure prototypes has revealed a non-perfect distribution of the glue layer between the components, such that further investigation and improvements to the gluing techniques will be carried out by the YIG.
- The DESY group has taken over the responsibility to design and construct a small functional prototype (30 cm x 50 cm) of a section of one of the endcap disks of the tracker. The prototype is foreseen to undergo thermal conductivity tests in order to prove the feasibility of the thermo-mechanical design. The gluing tests being performed by the YIG will provide important input to the design and assembly procedure of the functional

prototype.

Responsibilities of the group members:

M. Aldaya:

- Coordinator of the DESY CMS Top Quark Physics Group
- CMS coordinator of the combination of tt inclusive cross section results of the CMS and ATLAS Collaborations within the Top LHC Working Group
- CMS coordinator of the combination of tt differential cross section results of the CMS and ATLAS Collaborations within the Top LHC Working Group
- Convenor of the Top Quark Working Group of the 8th Annual Meeting of the Helmholtz Alliance „Physics at the Terascale“, DESY Hamburg (Germany), 1 – 3 Dec 2014

C. Diez Pardos:

- Contact person between the Top Quark Physics Analysis and Muon Performance Groups in CMS
- Coordinator of the working meetings of the DESY CMS Top Quark Physics Group

M. Savitskyi:

- Contact person between the Top Quark Physics Analysis and Monte Carlo Generator Groups in CMS

5) Financial Plan / Time Schedule

Can you comply with the financial plan and time schedule or do you see a need for adjustment?

The expenses for personell and travel, including the CMS operation fees, correspond to financial plan of the proposal. There is no need to adjust the financial plan or the time schedule.

6) Status

Do you hold a joint Junior Professorship or a W2/W3 Professorship? Do you aim for such a position? What is the status of your negotiations in this respect?

The group leader does not hold a junior professorship or a W2/W3 professorship. Negotiations aiming at such a position have not started yet.

7) Teaching Activities of the Group Leader

During the report period, the group leader has had the following teaching activity:

- Lecturer on “Top Quark Physics” at the DESY Summer Student Programme in August 2014.

8) Publications of the Group

Public presentations by the group members:

- 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
- M. Aldaya, *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, *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, *Combination of top quark physics results at the LHC*, ICHEP2014: 37th

- International Conference on High Energy Physics, Valencia (Spain), 2 – 9 Jul 2014
- 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

Relevant publications, approved public results, and publications in preparation:

- [1] CMS and ATLAS Collaborations, *Combination of ATLAS and CMS top quark pair cross section measurements in the emu final state using proton-proton collisions at $\sqrt{s} = 8$ TeV*, CMS Physics Analysis Summary CMS-PAS TOP-14-016 (2014) (corresponding author and editor: M. Aldaya)
- [2] CMS Collaboration, *Measurement of the tt production cross section in the emu channel in pp collisions at $\sqrt{s} = 7$ and 8 TeV*, journal publication TOP-13-004 in preparation (corr. author and editor: C. Diez Pardos)
- [3] CMS Collaboration, *Measurement of the differential top quark pair production cross section in pp collisions at $\sqrt{s} = 8$ TeV*, journal publication TOP-12-028 in preparation (corr. authors: M. Aldaya, C. Diez Pardos, editor: M. Aldaya)
- [4] CMS Collaboration, *Measurement of jet multiplicity distributions in tt production in pp collisions at $\sqrt{s} = 7$ TeV*, arXiv: 1404.3171 [hep-ex], Eur. Phys. J. C74 (2014) 3014 (corr. authors: C. Diez Pardos, M. Aldaya)
- [5] CMS Collaboration, *Measurement of tt production with additional jet activity and properties of the additional jets, including $tt+bb$, in the dilepton channel at $\sqrt{s} = 8$ TeV*, journal publication TOP-12-041 in preparation (corr. authors: C. Diez Pardos, M. Aldaya, editor: C. Diez Pardos)
- [6] CMS Collaboration, *Determination of the normalized invariant mass distribution of $tt+1jet$ and extraction of the top quark mass*, preliminary result in preparation (corr. author and editor: C. Diez Pardos)
- [7] CMS Collaboration, *Search for the associated production of the Higgs boson with a top-quark pair*, arXiv:1408.1682 [hep-ex], J. High Energy Phys. 09 (2014) 087 (corr. author: C. Diez Pardos)

9) External Funding

10) Patent Applications

No. of pending/granted patents

11) Awards received by Group Members / Professorship Appointments offered to Group Leader