# Final Report

| | |
|---|---|
| **Funding Programme:** | Helmholtz Young Investigators Groups |
| **Project ID No.:** | VH-NG-503 |
| **Project Title:** | Probing Electroweak Symmetry Breaking at LHC: Higgs Physics with the CMS Detector |
| **Group Leader:** | Alexei Raspereza |
| **Helmholtz Centre:** | DESY |
| **Participating University:** | Karlsruhe Institute of Technology |
| **Report Period:** | 1.03.2009 – 28.02.2014 |

## 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.*

Main achievements of the Young Investigators Group encompass preparations for the Run-I data-taking with the Compact Muon Solenoid (CMS) detector at the Large Hadron Collider (LHC), construction and operations of the CMS detector components and physics analyses exploring mechanism of electroweak symmetry breaking with the CMS data at the LHC.

During the first year of the LHC physics program in 2010, the group has taken an active part in the commissioning of the tracking system of the CMS detector as well as in validation of the track reconstruction software. The careful study of production of the strange and charm resonsances with the first proton-proton collision data at 7 TeV allowed to calibrate tracking detector, measure track and secondary vertex reconstruction efficiencies and significantly improve CMS reconstruction tools.

The group has also contributed to the construction, installation and operation of the beam condition monitor of the CMS detector. This part of the detector is a key component to ensure safe performace of the inner tracking system, which plays crucial role in physics analyses pursued by the group.

The major achievement of the group was contribution to the CMS physics studies aimed at searches for the Higgs boson decays into fermions both in the context of the Standard Model (SM) and its Minimal Supersymmetric Extension (MSSM). The group has pionereed analysis, searching for the SM Higgs boson in decays to tau-leptons in the same lepton flavor final states, e.g. di-electron and di-muon channels. The analysis has been commissioned with the study of the inclusive Z boson production followed by decays of the Z boson into tau-leptons, leading to the first measurement of electroweak signals involving tau-leptons at the LHC.

Following the commissioning stage, the analysis has been further developed and optimized to search for the SM and MSSM Higgs bosons in decays to tau-leptons in various production modes and tau-lepton decay channels. In the context of these studies, the group has also participated in the development of lepton identification algorithms and background estimation methods, such as tau-lepton embedding technique employed for modelling of major background – the Z boson decays into tau-leptons. With these efforts, the group has contributed to the landmark CMS paper, which presented an evidence of the Higgs boson coupling to tau-leptons and first measurements of the Higgs boson properties in this channel.

In addition, the search has been also performed for the supersymmetric Higgs bosons, decaying to tau-leptons. Results of this search revealed no signal and stringent constraints on the MSSM parameters have been set.

The group has also played a leading role in the analysis, searching for neutral MSSM Higgs bosons produced in association with b-quarks and decaying into a b-quark pair. To make this channel accessible at the LHC, dedicated multi-jet triggers have been developed by the group.

These triggers implement online tagging of b-quark jets with the use of track impact parameter information. The analysis of the triple b-quark final states has been designed and performed by the DESY group in close collaboration with other CMS institutes to search for MSSM Higgs boson decays into b-quarks. The study has found no evidence of the MSSM Higgs boson signal yet and allowed to set stringent constraints on the MSSM parameters. This is the first time the measurements in the triple b-quark channel has been performed at the LHC.

## a. Work and Results Report

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

One of the main goals of the extrapolation of the TeV scale, which is currently probed at the LHC is elucidating mechanism of electroweak symmetry breaking. In the Standard Model of particle interactions as well as in its various extensions, the electroweak symmetry breaking is realized via Higgs mechanism, which generates masses of elementary particles and gives rise to one (in the SM) or several (e.g in MSSM) fundamental scalar particles – Higgs bosons.
Detailed exploration of the Higgs mechanism implies detection of the Higgs boson, measurement of its couplings to the Standard Model particles as well as its self-coupling, determination of its quantum numbers and confronting these measurements against the Standard Model and its various extensions. The Higgs physics program involves also search for additional Higgs states predicted by models with the extended Higgs sector, e.g. MSSM.
By the time when the YIG project started, the LHC was still in the commissioning phase, while no compelling evidence of the existence of the Higgs boson was found in data provided by previous experimental facilities, such as the Large Electron-Positron Collider at CERN and the TEVATRON proton-antiproton collider at Fermilab. In 2010 the LHC was put into operation, aiming for discovery of the Higgs boson and exploration of the Higgs mechanism or alternative scenarios of electroweak symmetry breaking. Enormous preparatory work had to be performed prior to the physics studies. This included calibration and commissioning of the CMS detector, design of triggers, used to record events compatible with the signatures of the Higgs boson signal, development and validation of event reconstruction and analysis software and measurements of the SM processes, constituting major backgrounds for the Higgs boson searches. Participation in these preparatory steps and contribution to the search for the SM and supersymmetric Higgs bosons along with the subsequent study of the Higgs boson properties in decays to fermions constituted the core of the YIG project.

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

As a multi-purpose apparatus, CMS detector provides particle physicist with experimental data for the exploration of the electroweak symmetry breaking mechanism and physics beyond the Standard Model. The activities of the group focused on several aspects of the CMS detector operation, event reconstruction and physics analysis of the CMS data. This included construction, installation and operations of the Fast Beam Condition Monitor of the CMS detector, development and validation of the event reconstruction algorithms and physics analyses, aiming at detection of the Higgs bosons, predicted by the SM and its various extensions, and studies of the Higgs boson properties.

***Hardware related activities: construction and operation of the beam condition monitor of the CMS Detector***

Most of the analyses, pursued by the group and described in the next sections of this Report, deal with the reconstruction of the Higgs boson, a fundamental particle, appearing as a result of spontaneous electroweak symmetry breaking. The Higgs boson is unstable and decay in other unstable particles, which are detected by the reconstruction of their decay vertices, displaced by few mm from the primary vertex. For robust reconstruction of secondary vertices

a highly precise and efficient track reconstruction is a necessary prerequisite. Key devices to support this are beam condition monitors. These devices are invaluable to protect inner tracking detectors of the experiment from adverse beam conditions and ensure low background rates. The fast beam monitor, BCM1F, was built and commissioned by the CMS DESY group and is operated with the strong support by students and post-docs from the YIG. It uses single crystal diamond sensors, radiation hard front-end electronics and optical signal transmission to the back-end fast Analog-to-Digital Converters (ADCs), scalers, Time-to-Digital Converters (TDCs) and Field-Programmable Gate Arrays (FPGAs). Eight modules, comprising a diamond sensor, a radiation hard pre-amplifier and a laser, are positioned on two ring-like carbon structures at both sides of the interaction point of the CMS experiment. The core back-end hardware and the data acquisition system has been developed by the DESY CMS group with an active participation of YIG members. Following installation and commissioning of BCM1F, the group has taken responsibility for maintaining and operation of the device as a part of activities of the Beam Radiation Monitor Detector Performance Group of the CMS Collaboration. During data-taking period in years 2010 – 2012, the system was operated without any interruption whenever there was beam in the LHC, delivering count rates of collision products and online beam halo measurements both to the CMS experiment and LHC operation center. With additional FPGA hardware, BCM1F was upgraded to a multi-purpose device, monitoring independently the luminosity delivered to the CMS experiment and the vacuum in the beam pipe.

***Commissioning of tracking system and validation of track reconstruction tools***

Most of the analyses, aiming at detection of the Higgs boson and measurements of its properties, rely on precise reconstruction of charged particles and decay vertices in the CMS tracking system. In particular, the study of the Higgs decays into tau-lepton and b-quark pairs requires superb performance of the tracking system and efficient track reconstruction algorithms. The precise reconstruction of isolated charge particle momenta is a key step in identification of tau-leptons and measurement of their momentum, whereas measurement of track impact parameters with respect to primary interaction point and decay vertices of hadrons is crucial for identification of b-quark jets.
The group took an active part in the CMS tracker commissioning with studies of the strange and charm hadron production in the first proton-proton collisions. These analyses tested CMS tracker performance and validated track reconstruction software. The studies performed by the group enabled measurement of the track and decay vertex reconstruction efficiencies, thereby providing a valuable input for various physics studies performed later by the CMS Collaboration including also analyses, which searched for the Higgs boson and measured its properties.

***Measurement of the inclusive Z boson production with subsequent decays of Z boson into tau-lepton pairs***

The process of the Z boson production followed by Z decays into a pair of tau-leptons plays an important role in the physics program at the LHC. Firstly, this channel provides a test of the Standard Model, e.g. the hypotheses of lepton universality, the decay properties of tau-leptons and higher order theoretical predictions for the Z boson production cross sections in proton proton collisions. Secondly, it provides an experimental sample for the commissioning of tau-lepton triggers and identification algorithms. Thirdly, the measurement of Z decays into tau-leptons is important as this process constitutes a major source of background to the search for the Higgs bosons decaying into tau-leptons both in the context of the SM and its supersymmetric extensions. The Young Investigators Group has developed a novel analysis, in which tau-lepton pairs are selected and reconstructed in the channel involving two muons and missing transverse energy. The analysis in this channel faces two main challenges: large background which comes from the direct Drell-Yan di-muon production and relatively small topological branching fraction of the tau-lepton pair decays into two muons. The likelihood

based multi-variate selection has been worked out, which efficiently discriminated between di-muon and di-tau decays of the Z boson. The reconstructed spectrum of the invariant mass of the muon pairs has been used to measure the Z boson production cross section in this channel. Additionally, the group also contributed to the development of statistical tools, employed in combination of the $Z \rightarrow \tau\tau$ measurements performed by CMS in different decay modes of tau-lepton pairs. This combination marked one of the first measurements of the electroweak signals involving tau-leptons at the LHC. The measurements has been used to validate and tune Monte Carlo generators, simulating Z boson inclusive production in the proton-proton collisions at the LHC energies. As a by product of these studies, the efficiency of the tau-lepton identification was measured, providing valuable information to all CMS analyses performed on the first LHC data and relying on the reconstruction of tau-leptons.

***Evidence for the Higgs boson decays into tau-leptons***

In July 2012, ATLAS and CMS Collaborations announced the discovery of a particle resembling the long-searched Higgs boson. Since then collaborations have performed a number of measurements in the bosonic decay modes using full set of Run-I LHC data. These studies have indicated that the properties of the newly discovered state are consistent with those expected for the Standard Model Higgs boson. However it was not clear until recently if the new boson couples also to fermions. Since discovery of a Higgs boson its decay rate to fermions remained the most eagerly awaited measurements in particle physics, as it would further extend our knowledge about theoretical mechanism which generates masses of elementary particles. Presently, these measurements can only be achieved by studying decays of the Higgs boson into tau-leptons and b-quarks. The Young Investigators Group has made significant contribution to the analysis, probing Higgs boson coupling to tau-lepton with 25 $fb^{-1}$ of proton-proton collision data collected by CMS experiment at center-of-mass energies of 7 and 8 TeV. In collaboration with other CMS institutes, members of the group improved and validated dedicated electron identification algorithm based on multi-variate approach. The algorithm exploited calorimetric and tracker information which were used as an input to the Boosted Decision Tree (BDT). The BDT output was then used to select electron candidates, yielding sample of genuine electrons with high selection efficiency and purity. The algorithm was extensively used in the CMS analyses of tau-lepton pair decay topologies with electrons in final states. Another important contribution of the group was continuous development and maintenance of the software tools for modelling of the Z boson production with subsequent decay of the Z boson into a tau-lepton pair. This was achieved using the so called tau-lepton embedding technique. The method is based on selection of the pure sample of the di-muon decays of the Z boson in data with subsequent substitution of two muons by simulated tau-lepton decays. The simulated decay products of tau-leptons are then overlaid with the original data event, resulting in reduction of systematic uncertainties related to the simulation of pileup interactions (e.g. interactions occurring in the same bunch crossing of the proton beams), underlying event, missing transverse energy and properties of jets accompanying the Z boson production. The group has systematically studied possible biases introduced by the method and carried responsibility for the central production of the $Z \rightarrow \tau\tau$ embedded samples for the CMS analyses.
The analysis of the Standard Model Higgs boson decays to tau-leptons by CMS is an extraordinary difficult measurement, which employs about 30 different topologies, exploiting minute differences in events between various Higgs production modes and tau-lepton decay channels. The Young Investigators Group performed an analysis of the tau-pair decay channels, resulting in topologies with two electrons or two muons. In the course of these studies ideas and methods applied in the analysis of Z decays into tau-leptons have been further developed and used in the Higgs studies. In particular, a multi-variate approach to discriminate the Higgs boson signal from major background processes has been improved by exploiting jet related variables, sensitive to the Higgs boson production via vector-boson-fusion process, tau-lepton decay length information and variables sensitive to kinematics of neutrinos resulting from leptonic tau decays. Sensitivity of the analysis has been further enhanced by

introducing event categorization, exploiting various Higgs boson production mechanisms. In each event category, a global event discriminant, based on a multi-variate approach, was used to extract the signal from the Higgs boson decays to tau-leptons. The group has also developed a novel analysis, searching for the Higgs boson production in association with the W boson. In this analysis the W boson is identified via its leptonic decays, while the $H \rightarrow \tau\tau$ decays are reconstructed exploiting semi-hadronic decay signatures of both tau-leptons. A multi-variate analysis approach has been used to suppress the dominant backgrounds. The invariant mass of the tau-lepton visible decay products was used to extract signal in this channel. After combining all the channels studied, the CMS collaboration has observed an evidence of the SM-like Higgs boson with the mass close to 125 GeV, decaying to tau-leptons. The observed signal corresponds to the statistical significance of 3.2 standard deviations above background predictions, meaning that the probability of having observed a fake signal is of the order of one permille. Using CMS data Higgs couplings to weak bosons and fermions were measured in the decay mode of the Higgs boson into a tau-lepton pair.

***Search for supersymmetric Higgs bosons produced in association with b-quarks and decaying to b-quark pairs***

Study of fermionic decays is also crucial in searches for additional Higgs states, expected in theories with the extended Higgs sector. The example is given by MSSM, which predicts two doublets of the complex scalar fields. The spontaneous symmetry breaking gives rise to five physical Higgs states: two neutral scalars, denoted h and H; one pseudo-scalar A; and two charged bosons, $H^{\pm}$. The cross-sections of the gluon-fusion and b-quark associated production processes of the neutral MSSM Higgs bosons are enhanced at high values of $\tan\beta$, making these processes very attractive for the MSSM Higgs boson searches. The group has contributed to the CMS search for MSSM Higgs bosons, decaying into tau-leptons by analyzing channels with two leptons (electron+muon and two muons) in the final states and performing statistical combination of the search results obtained in various tau-lepton decay modes. The search, performed on the CMS data collected at 7 and 8 TeV, revealed no signal and results of the analyses were translated into stringent constrains on the MSSM parameters. Also model-independent interpretation of the search results was performed by setting upper limits on the MSSM Higgs boson production cross-sections times branching fraction of decay into tau-leptons.

***Search for supersymmetric Higgs bosons produced in association with b-quarks and decaying to b-quark pairs***

The group has also played a leading role in the analysis, searching for heavy neutral MSSM Higgs bosons produced in association with b-quarks and decaying into a b-quark pair. The overwhelming QCD background and efficient triggering of signal events present major challenges for this study. Members of the group together with collaborators from other CMS institutes have developed dedicated triggers, recording events with multiple b-quark jets. The analysis, designed by the YIG, searched for a resonant structure in the invariant mass spectrum of the two leading b-quark jets in the sample of selected events with one additional spectator b-quark jet. The QCD multi-jet background is measured from data, using sample of events with three jets, two of which are tagged as b-quark jets, and extrapolating prediction to the triple b-quark jet sample by modeling tagging of the third jet. The study, performed on ~ 4 $fb^{-1}$ of data collected by CMS at 7 TeV, revealed no signal. The sensitivity of the search has been significantly improved by combining results obtained by the group with the analysis performed by collaborators from INFN in Padova. The latter study employed trigger, recording multi-jet events with signatures of muonic b-hadron decays. No evidence of signal is found in the combination of the two analyses and results of the search were translated into constraints on MSSM parameters. The upper 95% confidence level limit on $\tan\beta$ as a function of the CP-odd Higgs boson mass, $m_A$, has been extracted in several MSSM benchmark scenarios. In

addition limits on the production cross section times the Higgs boson branching fraction into b-quark pairs have been set for various hypothetical Higgs boson masses. The analysis attracted a lot of interest from theorists, who confronted results of the search against various theoretical models. Sensitivity of the search, performed by CMS on the LHC data collected at 7 TeV, significantly surpassed sensitivity of similar search by D0 and CDF experiments at TEVATRON. This was the first time the measurement of this kind had been performed at the LHC.

**c) Outlook on future work, sustainability (max. 2 DIN A4 pages)**

Owing gained experience, developed analysis frameworks and sustained manpower, the activities in the area of the Higgs physics will not fade away in the CMS DESY group with the end of the YIG project. Contrary, the scope of the Higgs studies has been significantly extended in comparison to the original proposal.

The discovery of a Higgs boson with a mass near 125 GeV and initial measurements of its properties with the Run-I LHC data is only the first step in exploration of the Higgs mechanism of spontaneous electroweak symmetry breaking. The measured properties of the discovered particle do not exclude the possibility that the observed boson is just one of several physical states expected in the models with the extended Higgs sector, such as MSSM or Next-to-Minimal Supersymmetric Standard Model (NMSSM). To address these scenarios, the CMS Collaboration initiated a number of analyses searching for the non-SM signatures both in production and decays of the Higgs bosons. The DESY CMS group takes an active part in this effort. The analysis, searching for the MSSM Higgs bosons produced in association with b-quarks and decaying into a b-quark pair, continues on 20 $fb^{-1}$ of data collected by CMS at center-of-mass energy of 8 TeV. The study benefits from new triggers, developed by the group to cope with higher rates of background processes due to increase in instantaneous luminosity, and advanced analysis strategy, extending sensitivity reach to the Higgs bosons with masses up to 1 TeV.

Two new analyses, searching for the light NMSSM Higgs states, have been started. To comply with the LEP and LHC constraints, this light boson must have reduced couplings to weak bosons and fermions. Hence, the dedicated search should exploit non-conventional production modes. The first of the two analyses searches for the NMSSM Higgs boson with a mass lower than the mass of the Z boson. The analysis looks for production of the Higgs boson in cascade decays of supersymmetric particles followed by decay of the boson into a pair of b-quarks. The second analysis searches for the lightest NMSSM Higgs scalar, $H_1$, with a mass in the range from 4 to 8 GeV, meaning that $H_1$ decays predominantly into tau-leptons. The analysis assumes that the discovered 125 GeV state is the second lightest NMSSM scalar $H_2$, and looks for the very light state in the cascade decays $H_2 \rightarrow 2H_1 \rightarrow 4\tau$. Both analyses are in advanced stage and will be completed before LHC Run-II will start. The results of these studies will probe large domain of the NMSSM parameter space and provide sensitivity to the NMSSM Higgs signal in certain class of models.

In parallel with ongoing analyses, searching for new Higgs bosons with the available Run-I LHC data, the LHC experiments are preparing for the LHC Run-II at energies of 13/14 TeV. The upcoming data will enable a more detailed study of a newly discovered Higgs state. Anticipated precision of the future measurements will allow to probe new physics through deviation from the SM predictions for the Higgs boson properties. Preparation for upcoming Run-II covers two aspects. First, efforts are being made to develop new triggers and re-optimize algorithms for reconstruction and identification of physics objects, such as leptons, jets, b-quark jets and missing transverse energy, in order to cope with larger number of pileup interactions and also higher trigger rates due to increased instantaneous luminosity. Secondly, new analyses are being developed to extend the measurements of the properties of the discovered boson and improve precision of these measurements.

The group contributes to the development of dedicated triggers for the analysis of channels,

involving tau-leptons and b-quark jets. In addition analyses are being designed to perform precise measurements of the Higgs properties in the H → ττ channel at 13-14 TeV, e.g. determination of the Higgs boson parity through the measurement of tau-lepton spin correlations. The group performs also feasibility studies with the aim to extend sensitivity of the search for supersymmetric Higgs bosons in decays to b-quarks and tau-leptons using future Run-II data.

In addition, the group will further contribute to the upgrade of the CMS tracking system and beam condition monitors in different upgrade phases, thus strengthening the leading role of DESY in the CMS upgrade program.

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

The results achieved by the group in the course of the YIG project are of high relevance for fundamental research but have no immediate application in the industrial use.

**2) 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.*

During the whole period of the YIG project, 2 post-doctoral researches (including group leader) and 6 PhD students contributed to the group activities.

After positive evaluation in 2012, the group leader obtained the staff position at DESY and is the principle collaborator (PC) of the Sonderforschungsbereich (SFB) project B9 "Probing the physics of electroweak symmetry breaking with results from the LHC", which is the joint effort of the DESY ATLAS and CMS groups, DESY Theory group and the CMS group at the University of Hamburg. The group leader is also holding coordination position in the MTauTau Working Group of the Helmholtz Alliance "Physics at the Terascale". This working group is meant to provide a forum across German experimental and theory groups for discussion of theoretical and experimental aspects of the Higgs boson physics, involving tau-leptons.

Dr. Roberval Walsh has temporary contract with DESY as post-doctoral researcher. During 2011-2012 he coordinated activities of the trigger sub-group within the B-Tagging Physics Object Group of the CMS Collaboration. In 2013 Dr. Walsh took over responsibility of coordinating activities of the CMS Detector Performance Group, maintaining and operating beam condition monitors of the CMS detector. At the moment he is applying for several positions to continue his research work with the CMS experiment.

Agni Bethani has successfully defended her PhD thesis "Neutral Higgs Boson Searches in the $H \rightarrow \tau\tau \rightarrow \mu\mu$ Decay Channel" at the Karlsruhe Institute of Technology with magna cum laude in 2013. She is currently holding short-term employment post-doctoral position at the Rutherford Appleton Laboratory in London and applying for a post-doctoral positions to continue her research work with one of the LHC experiments.

Jakob Salfeld-Nebgen joined group as PhD student in 2012 to work on analysis searching for the Higgs boson decays to tau-leptons in the di-electron channel. His thesis is close to completion and will be defended at the University of Hamburg tentatively in summer 2014.

Igor Marfin is employed as PhD student in the CMS group at DESY-Zeuthen since 2011. His PhD topic is concerned with the search for MSSM Higgs bosons produced in association with b-quarks and decaying to b-quark pairs. Starting from May 2013 he holds position of trigger

sub-group coordinator within the CMS B-Tagging Physics Object group of the CMS Collaboration. Igor Marfin has recently completed his thesis and submitted it to the Technical University of Cottbus. His PhD defence is scheduled for summer 2014.

Armin Burgmeier joined CMS group at DESY as a PhD student in 2011. He is currently finalizing his thesis on searches for the CMS Higgs boson produced in association with the W boson and decaying into a tau-lepton pair.

Luigi Calligaris is employed as a PhD student at DESY since 2011. He is currently working on analysis searching for the MSSM Higgs bosons decaying into tau-lepton pairs in the electron+muon channel. The goal of his PhD project is to improve sensitivity to the MSSM Higgs boson signal in this channel and prepare analysis for LHC data-taking at 13/14 TeV.

Gregor Hellwig joined the group in 2012 and is currently working on analysis, searching for the light NMSSM Higgs boson produced in cascade decays of supersymmetric particles and decaying into a b-quark pair.

Three post-doctoral researches has joined group recently.
Dr. Matthias Schroeder leads analysis efforts in the area of the MSSM Higgs boson searches in the decay mode to b-quarks. His service to the CMS Collaboration is provided by work on CMS tracker alignment.
Dr. Pooja Saxena is involved in preparation of the analysis aimed at measurement of the Higgs boson parity in the $H \rightarrow \tau\tau$ decay channel. In addition, she contributes to the CMS Hadron calorimeter upgrade, an effort where the DESY CMS group plays an important role.
Dr. Aruna Nayak works on development of dedicated tau-lepton triggers for the LHC Run-II data-taking and takes part in the tracker upgrade effort. He also plans to make a contribution to the measurements of the Higgs boson properties in decays to tau-leptons with the future Run-II LHC data.

A number of PhD positions have been advertised in order to reinforce manpower of the CMS DESY Higgs group. Successful candidates will contribute to preparations for the LHC Run-II and Higgs analyses with the first proton-proton collision data at 13/14 TeV.

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

The group is well represented in the physics community by about 6 presentations per year by the group members at the international conferences and public seminars. The group sustained its visibility within the CMS collaboration by continuous contribution to the activities of the Physics Analysis, Physics Object Reconstruction and Detector Performance groups of the CMS experiment. The physics results and ongoing activities of the group along with the job announcements are highlighted on a dedicated web page of the group.

**4) 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 activities of the group are well embedded in the physics programme of the LHC groups at DESY. In the course of the YIG project, the group has established close ties with a number of institutes within Germany and abroad. Close and fruitful collaboration with the Karlsruhe Institute of Technology is demonstrated by common analysis of the di-lepton final states in the context of the SM Higgs boson studies in the decay channel to tau-leptons. This collaboration resulted in significant contribution to the CMS publication, presenting evidence of the Higgs boson coupling to tau-leptons.

In cooperation with the University of Zurich and Institute of Theoretical and Experimental Physics (Moscow), the group pursues MSSM Higgs boson searches in decays to b-quarks and prepared publication of the search results obtained from the analysis of the CMS data collected at 7TeV.
A number of analyses, searching for the NMSSM Higgs boson signals, are being performed in a close cooperation with the DESY Theory group and the CMS group at the Univeristy of Hamburg. These analyses along with the research work on interpretation of the Higgs boson measurements and results of the supersymmetric Higgs searches within various theoretical models, constitute major part of the Sonderforschungsbereich (SFB) project B9 „Probing the physics of electroweak symmetry breaking with results from the LHC“, which is the joint effort of the DESY CMS and ATLAS groups, the CMS group at the University of Hamburg and DESY Theory group. The YIG leader is one of the principle collaborators in this project.

## 5) List of Publications

***Major journal publications***

[CMS Collaboration] Eur. Phys. J. C70 (2010) 1165-1192 [arXiv:1007.1998], *“CMS Tracking Performance Results from early LHC Operation”*

R.S. Schmidt *etal*, JINST 6 (2011) C01004 [arXiv:1012.3580], *“Performance of the Fast Beam Conditions Monitor BCM1F of CMS in the first running periods of LHC”*

[CMS Collaboration] JHEP 1108 (2011) 117 [arXiv:1104.1617], *“Measurement of the Inclusive Z Cross Section via Decays to Tau Pairs in pp Collisions at 7 TeV”*

[CMS Collaboration] Phys. Lett. B716 (2012) 30-61 [arXiv:1207.7235], *“Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC”*

[CMS Collaboration] JHEP 1306 (2013) 081 [arXiv:1303.4571], *“Observation of a new boson with mass near 125 GeV in pp collisions at 7 and 8 TeV ”*

[CMS Collaboration] Phys. Lett. B722 (2013) 207-232 [arXiv:1302.2892], *“Search for a Higgs boson decaying into a b-quark pair and produced in association with b quarks in proton-proton collisions at 7 TeV”*

[CMS Collaboration] [arXiv:1401.5041], accepted by JHEP, *“Evidence for the 125 GeV Higgs boson decaying to a pair of tau leptons”*

***Preliminary public results***

[CMS Collaboration] CMS Physics Analysis Summary HIG-13-021 *“Search for Neutral MSSM Higgs Bosons Decaying to Tau Pairs in pp Collisions”*

***Selected conference contributions***

Roberval Wlash for the CMS Collaboration, *“Performance of the CMS Fast Beam Conditions Monitor”*, proceedings of the 2010 IEEE Nuclear Science Symposium and Medical Imaging Conference, Knoxville, Tennessee, October 30 – November 6, IEEE Nucl. Sci. Symp. Conf. Rec. 2010 (2010) 1569-1572

Igor Marfin for the CMS Collaboration, *“Search for Higgs Boson production in association with b-quarks at CMS in pp collisions”*, proceedings of 32nd International Symposium on Physics in Collision (PIC 2012), Strbske Pleso, Slovakia, September 12 – 15 2012, [arXiv:1301.4412]

Jakob Salfeld-Nebgen for the CMS Collaboration, *"Search for the Higgs boson decaying into tau pairs"*, proceedings of 33rd International Symposium on Physics in Collision (PIC 2013), Beijing, P. R. China, September 3 – 7 2013, [arXiv:1403.0365]

***Dissertations***

Agni Bethani, "*Neutral Higgs Boson Searches in the H → ττ→ μμ Decay Channel*", Karlsruhe Institute of Technology, July 2013, Ph.D. Thesis, DESY-THESIS-2013-047