Mid Term Report 2010

Type of the project	Helmholtz-(Hochschul-) Nachwuchsgruppe
Support Number	VH-NG-503
Topic	Probing Electroweak Symmetry Breaking at LHC: Higgs Physics with the CMS Detector
Scientist in charge	Dr. Alexei Raspereza
Helmholtz Center	DESY
University Partner	University of Karlsruhe
Reference period	1.04.2010 – 31.03.2011

1. Introduction

The Young Investigators Group VH-NG-503 has started its work on March 1st 2009. During the past year three more Postdocs have joined the group as part time associate members. The activities of the group are centered at DESY Hamburg and focus on operations of the CMS detector at LHC and physics analysis of the CMS data. As of April 2011 the following researches have contributed to the group activities.

Members of the Group	*Position*	*Activities*
Dr. Alexei Raspereza	Group Leader	Coordination of the group activities, validation of the CMS tracking tools, study of the Z boson production and searches for neutral MSSM Higgs bosons in decays into tau leptons and b-quarks
Dr. Roberval Walsh	Postdoc	Operations of the Fast Beam Condition Monitor (BCM1F) of the CMS detector, analysis of CMS data in context of searches for MSSM Higgs bosons decaying to b quarks, study of D meson production in proton proton collisions
Agni Bethani	PhD student, DESY Hamburg	Study of the Z boson production and searches for MSSM Higgs bosons in decays to tau leptons

Associate members of the Group		
Igor Marfin	PhD student, DESY Zeuthen	Analysis of CMS data in context of searches for MSSM Higgs bosons decaying to b quarks, calibration of b-tagging algorithms
Dr. Ivan Glushkov	Postdoc	Study of D meson production in proton proton collisions
Dr. Caroline Riedl	Postdoc	Analysis of CMS data in the context of searches for the MSSM Higgs bosons decaying to tau leptons, development of DQM tools
Dr. Michele Rosin	Postdoc	Analysis of the CMS data in the context of searches for the MSSM Higgs bosons in decays to tau leptons
University Partner		
Prof. Dr. Thomas Mueller, Prof. Dr. Günter Quast	University of Karlsruhe, Karlsruhe Institute of Technology	

2. Activities of the Young Investigators Group

As a multi-purpose apparatus, CMS detector [1] 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 Young Investigators Group focus on several aspects of the CMS detector operation, event reconstruction and physics analysis of CMS data. This includes operation of the Fast Beam Condition Monitor of the CMS detector, validation of event reconstruction algorithms, and physics analyses aiming at measurements of electroweak processes, detection of Higgs bosons and studies of open charm production in proton proton collisions.

3. Operations of the Fast Beam Condition Monitor

The CMS Fast Beam Condition Monitor (BCM1F) is one of the subsystems of the CMS Beam Radiation Monitoring (BRM) [2]. The BMC1F detector monitors the beam-halo flux on a bunch-by-bunch basis. It consists of two planes installed around the beam pipe located at $z = \pm 1.8$ m from the interaction point. Each plane has four modules with 5x5 mm^2 radiation hard single crystal diamond sensors (sCVD) and radiation hard front-end electronics. Owing its ultrafast response, device can quickly react to the changes in the beam conditions and provide relevant information to the LHC operation team.

In the past year Dr. Roberval Walsh had been contributing to the operations of BCM1F together with the BCM1F group at DESY-Zeuthen and the BRM group at CERN. During 2010 data-taking period he took shifts and performed duties of expert-on-call for the CMS beam conditions and radiation monitoring group at CERN and participated in the development and maintenance of the software for the data acquisition of the time-to-digital converters (TDCs), a part of BCM1F readout system, which provides online information on

the beam conditions for the CMS shift crew. Dr. Walsh has been also performing offline analysis of the BCM1F data to monitor beam conditions during data-taking by CMS in the year 2010.

4. Physics Studies

Physics studies of the Young Investigators Group address three main topics:

- investigation of the *Z* boson production followed by decays of *Z* into tau leptons;
- analysis of the CMS data in the context of searches for neutral supersymmetric Higgs bosons decaying into tau leptons and b quarks;
- study of open charm production in proton proton collisions.

4.1 Study of Z Boson Production Followed by $Z \rightarrow \tau\tau$ in Dimuon channel

The process of *Z* boson production followed by *Z* decays into a pair of tau leptons plays an important role in the physics program at 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 *etc*. Secondly, it provides an experimental sample for the commissioning of tau lepton triggers and identification algorithms. Thirdly, the measurement of $Z \rightarrow \tau\tau$ events is important as these constitute a major source of background to the search for neutral supersymmetric Higgs Bosons decaying to tau leptons. Until recently three final states, defined by the decay modes of tau lepton pairs, have been studied:

- muon + hadronically decaying tau [3];
- electron + hadronically decaying tau [3] and
- electron + muon [4] channels.

The Young Investigators Group has developed a novel analysis, in which tau lepton pairs are selected and reconstructed in the channel $\tau\tau \rightarrow 2\mu 4\nu$. These events are characterized by two muons and missing transverse energy. The analysis in this channel faces two main challenges:

- large background which coming from Drell-Yan dimuon production;
- relatively small topological branching fraction of the $\tau\tau \rightarrow 2\mu 4\nu$ decays (only 3% of all possible tau pair decays).

The likelihood based multivariate selection has been developed, which exploits a set of variables, discriminating between $Z \rightarrow \mu\mu$ and $Z \rightarrow \tau\tau$ events. The distribution of the dimuon invariant mass after final selection is shown in Fig.1.

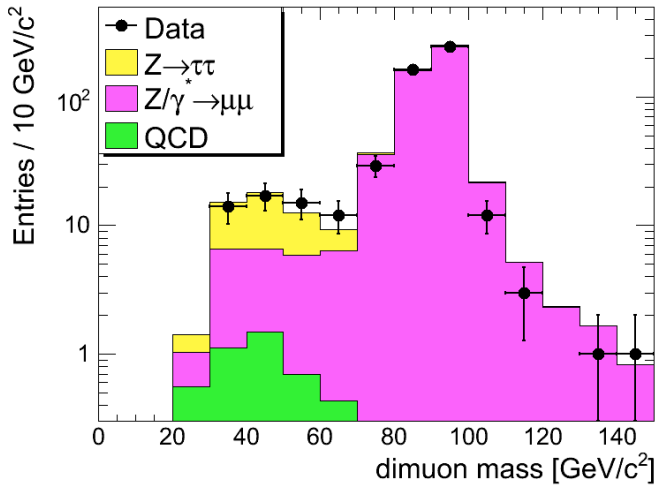

Figure 1: Distribution of the dimuon invariant mass in the sample of selected $Z \rightarrow \tau\tau \rightarrow 2\mu 4\nu$ candidates. CMS Data (dots) are compared to MC predictions for different Standard Model processes (filled histograms).

A clear signal has been established in the $\tau\tau \rightarrow 2\mu 4\nu$ decay mode. The results of the analysis have been combined with other channels to measure *Z* boson production cross section and determine identification efficiency of the

hadronically decaying tau leptons as shown in Fig.2. With the analysis in the dimuon channel, documented as CMS Analysis Note [5], the Young Investigators Group contributed to the CMS paper on the measurement of the inclusive Z boson production cross section followed by $Z \rightarrow \tau\tau$ decays in proton proton collisions at 7 TeV [6].

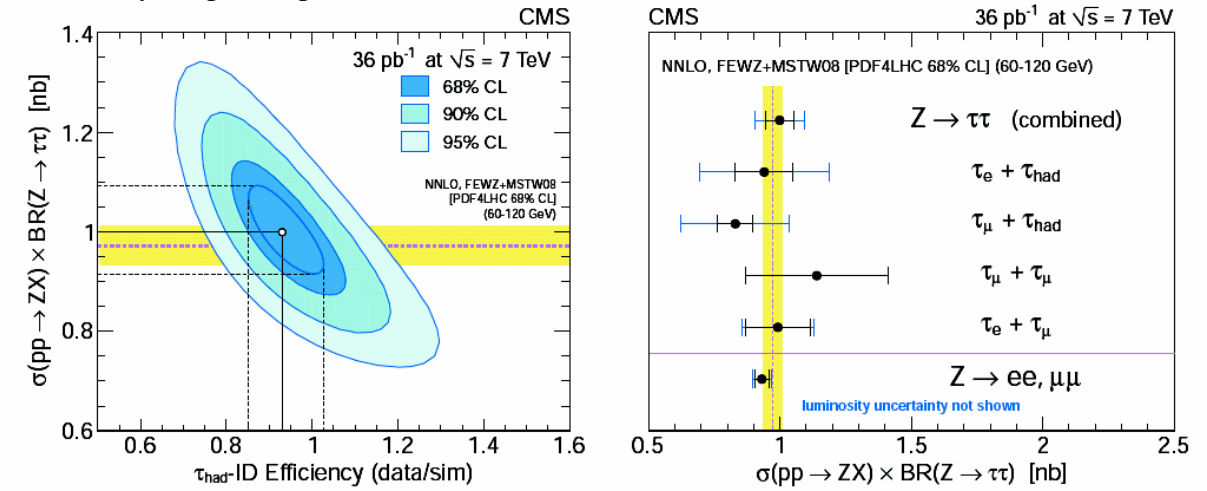

Figure 2: Contour in the cross section – τ-id efficiency plane from the combined fit (left). Summary of the measured $Z \rightarrow \tau\tau$ cross sections in the four final states: $e+\tau_{had}$ $\mu+\tau_{had}$, $e+\mu$ and $\mu+\mu$. The extracted cross-section from the combined fit and the NNLO theoretical prediction are also shown (right).

4.2 Searches for Neutral MSSM Higgs Bosons

Exploration of the Electroweak Symmetry Breaking (EWSB) mechanism is one of the main goals of the physics program at LHC. In contrast to the Standard Model, where EWSB is generated by one Higgs doublet and gives rise to one additional physics state – neutral Higgs boson – Minimal Supersymmetric Standard Model (MSSM) postulates two Higgs doublets resulting in five physical states:

- two neutral CP-even Higgs bosons, h and H;
- one neutral CP-odd Higgs boson A;
- two charged bosons, $H^{\pm}$.

Along with the Standard Model Higgs boson, Higgs bosons of MSSM are also subject of searches at LHC.

4.2.1 MSSM Higgs Searches in Decays to Tau Leptons

The study presented in Section 4.1 served for commissioning of the inclusive searches for neutral MSSM Higgs bosons decaying into tau leptons. Two production mechanisms are considered:

- gluon fusion, $gg \rightarrow \Phi$ (Φ=h, H, A) and
- b-quark associated Higgs boson production, $gg \rightarrow bb\Phi$.

The likelihood based multivariate analysis has been further developed to enhance discrimination between Z bosons decaying either into muon or tau lepton pairs, and neutral Higgs bosons decaying into tau leptons. The dedicated procedure [7], reconstructing invariant mass of tau lepton pairs, has been employed together with the visible mass of muon pairs to distinguish signal from background processes. No evidence for MSSM Higgs boson production was found in data collected by CMS in 2010, and results of the analysis have been translated into limits on the MSSM Higgs boson production cross section as shown in Fig.3. The study has been documented as CMS Analysis Note [8]. The developed analysis has been

reviewed and approved by the CMS Higgs Analysis Group and will be used to study 2011 data in the context of searches for neutral MSSM Higgs bosons decaying into tau leptons.

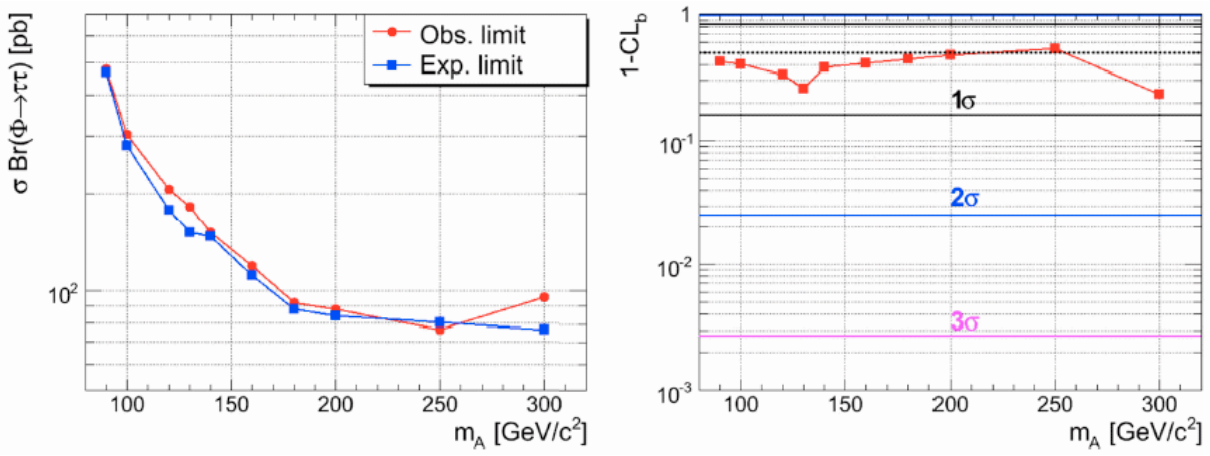

Figure 3: Expected and observed limits on the inclusive production cross section of the neutral MSSM Higgs bosons, σ(pp→Φ)xBr(Φ→ττ), as a function of the CP-odd Higgs boson mass, m_A, obtained from the analysis in the ττ→2μ4ν channel (left). The dependence of p-value, quantifying consistency of the Higgs boson search results with the "background-only" hypothesis, on m_A (right).

4.2.2 MSSM Higgs Searches in Decays to b-quarks

The group is also designing analysis aiming at detection of b-quark associated MSSM Higgs boson production followed by Higgs boson decays into b-quarks, *(b)bΦ→(b)bbb*. The analysis will select events with at least three b-jets as in majority of cases the fourth leading b-jet is expected to have very low transverse momentum making reconstruction of this jet extremely difficult. In the first step of the studies the emphasis was put on the development of the dedicated trigger for online selection of the *(b)bΦ→(b)bbb* signal events. A new High Level Trigger has been proposed by the Young Investigators Group for selection of three jet events with at least two jets being tagged as b-jets. The trigger exploits track impact parameters and information on reconstructed muons coming from the heavy flavor hadron decays. Anticipated low rate at high LHC luminosities along with a reasonable signal efficiency makes the proposed trigger one of the most favored solutions considered by the CMS Higgs Analysis Group for the online selection of the *(b)bΦ→b(bbb)*events. In parallel with the trigger development, the group designs the analysis strategy to search for the *(b)bΦ→(b)bbb* signal and performs feasibility studies and analysis optimization using Monte Carlo simulation.

4.3 Studies of Open Charm Production in Proton Proton Collisions

The analysis of open charm production has evolved in the context of b-tagging performance studies. The analysis was initially designed to test PYTHIA predictions for the *D* meson yields in hard QCD events. Weakly decaying *D* mesons produce tracks displaced with respect to primary interaction vertex, thus contributing selected sample of b-jets. Therefore accurate modeling of *D* meson production rates and kinematics is of utmost importance for understanding of b-tagging performance. The Young Investigators Group has developed analysis, studying *D* meson production in association with jets. The four charm mesons, D^0, D^+, $D^*(2010)^+$ and D_S^+ (and charge conjugate states) have been reconstructed exploiting the following decay modes:

- $D^0 \rightarrow K^- + \pi^+$;

- $D^+ \rightarrow K^- + \pi^+ + \pi^+$;
- $D^*(2010)^+ \rightarrow D^0 + \pi^+$;
- $D_S{}^+ \rightarrow \varphi + \pi^+$, $\varphi \rightarrow K^+ + K^-$.

The reconstructed D mesons have been associated to jets based on proximity in η-φ plane. Fig.4 shows as an example the signal in the $D^*(2010)^+ \rightarrow D^0 + \pi^+$ decay channel and measured $D^*(2010)^+$ yield per reconstructed jet in bins of jet transverse momentum. These measurements provided valuable inputs for tuning of Monte Carlo generators and validation of b-tagging performance in Monte Carlo simulation. The analysis is currently being extended to measure the ratio of inclusive production cross sections between charged mesons D^+, $D^*(2010)^+$, $D_S{}^+$ and neutral meson D^0. This study will provide crucial test of the Heavy Quark Effective Theory.

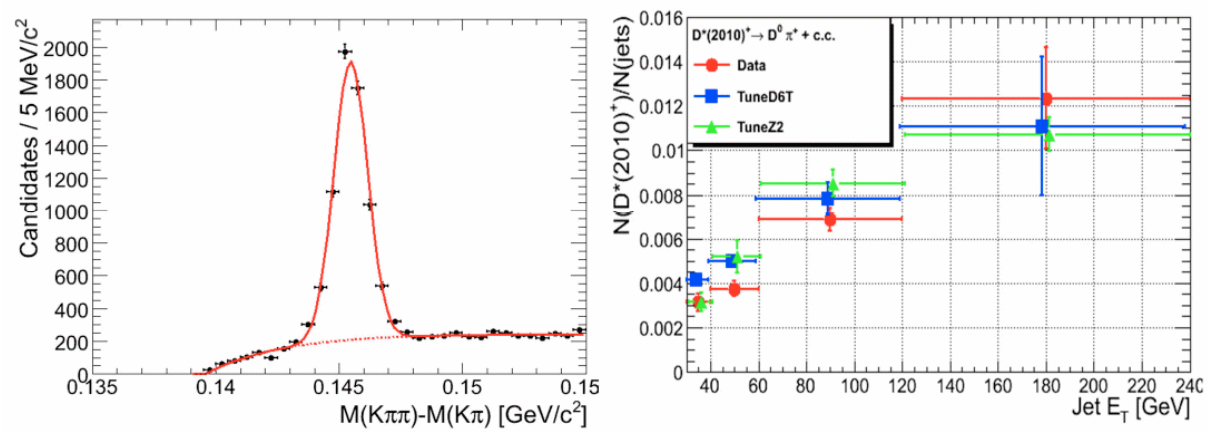

Figure 4: The signal reconstructed in the decay channel $D^*(2010)^+ \rightarrow D^0+\pi^+$ (and charge conjugate mode) with 36 pb^{-1} of CMS data collected in the year 2010 (left). The yield of $D^*(2010)^+$ mesons per reconstructed jet measured in data (dots) and compared to PYTHIA predictions based on two different Monte Carlo tunes: TuneD6T (squared) and TuneZ2 (triangles) (right).

5. Calibration of B-tagging Algorithms

Identification of b-jets will be the key ingredient of the analysis, searching for the b-quark associated neutral Higgs boson production followed by Higgs decay to b-quarks. As a part of activities related to the search for MSSM Higgs boson decays to b-quarks, the Young Investigators Group is involved in calibration of b-tagging algorithms using top pair production events. The analysis in semi-muonic channel has been fully established and tested with the first collision data. It has been demonstrated that b-tagging algorithms can be calibrated with a precision of few percent using one hundred inverse picobarn of data in the analysis of semi-muonic channel only. The analysis is being extended to include other modes of top pair decays, namely semi-electron and dilepton channels. Further improvements are being implemented to handle sizable pile-up effects at high instantaneous luminosities expected during LHC run in 2011.

6. Cooperation with the University Partner (Karlsruhe University and Karlsruhe Institute of Technology)

The Young Investigators Group closely cooperates with the CMS Group of the Karlsruhe Institute of Technology (KIT) on analyses involving tau leptons and b-jet identification. The joint meetings between the members of the Young Investigators Group and

members of the CMS KIT group are held every week to discuss the progress of analyses with tau leptons. As a result of close cooperation between two groups, data-driven methods for evaluation of the *Z+jets* and QCD backgrounds for the MSSM Higgs boson searches in decays to tau leptons have been developed. Presently two groups are working in close collaboration on the development of Level-1 and High Level Jet Triggers exploiting b-tagging information. This kind of triggers are designed for the online event selection in searches for the hypothetical $(b)b\Phi\rightarrow(b)bbb$ signal discussed in Section 4.2.2.

7. Analysis Notes, Publications and Presentations

For the reference period the Young Investigators Group has contributed to the following CMS publications and Analysis Notes:

1) *"Measurement of the Inclusive* $Z\rightarrow \tau^+\tau^-$ *Cross Section in pp Collisions at 7 TeV",* CMS Collaboration, arXiv:1104.1617 [hep-ex], submitted to **JHEP**;
2) *"Measurement of* $\sigma(pp\rightarrow Z)\cdot Br(Z\rightarrow\tau\tau)$ *in the Dimuon Channel with CMS in pp Collisions at 7 TeV",* A.Bethani *etal*, CMS Analysis Note AN-2010/446.
3) *"Search for Neutral Higgs Bosons Decaying into Tau Leptons in the Dimuon Channel with CMS in pp Collisions at 7 TeV",* A. Bethani *etal,* CMS Analysis Note AN-2011/140.

The following presentations have been given by the members of the group:

1) *"Performance of the CMS Fast Beam Condition Monitor",* R. Walsh, talk given at IEEE Conference, Knoxville, November 3rd 2010;
2) *"Measurement of* D^+ *Lifetime with First Collision Data at CMS",* R. Walsh, talk given at the FSP-CMS Meeting, Aachen September 8th 2010;
3) *„Study of* $Z\rightarrow\tau\tau$ *in Dimuon Channel with CMS in pp Collisions at 7 TeV",* A. Bethani, talk given at FSP-CMS Meeting, Aachen, September 8th 2010;
4) *"Study of B-tagging Efficiency in ttbar Events in the CMS Experiment",* I. Marfin, talk given at DPG Meeting, Karlsruhe, March 29th 2011;
5) *"Study of the Z Boson Production and Search for the Neutral Supersymmetric Higgs Bosons in the Decay Channel* $Z(H/A)\rightarrow\tau\tau\rightarrow 2\pi 4\nu$ *with the First LHC Data Collected with the CMS Detector",* A. Bethani, talk given at DPG Meeting, Karlsruhe, March 19th 2011.

8. Financial Status

The financial status report is attached as a separate MS Excel document.

References

[1] CMS Collaboration, R. Adolphi *et al.*, ***JINST* 3** S08004 [SPIRES].
[2] A. Bell et al., **Nucl. Instrum. Meth. A614**: **433-438, 2010.**
[3] M. Bachtis *etal*, CMS Analysis Note, AN-2010/387.
[4] G. Bauer *etal*, CMS Analysis Note, AN-2010/465.
[5] A. Bethani *etal,* CMS Analysis Note, AN-2010/446.
[6] CMS Collaboration, ArXiv:1104.1617 [hep-ex], submitted to **JHEP**.
[7] J. Conway *etal,* CMS Analysis Note, AN-2010/460.
[8] A. Bethani *etal,* CMS Analysis Note, AN-2011/140.