Attachment nr 2b to "Wniosku o wszczęcie postępowania habilitacyjnego"
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Autoreferat
Presentation of research achievements

Contents

1 Personal data

Surname and name: Artur Kalinowski

2 Education

2002: M.Sc. in physics, University of Warsaw, College of Inter-Faculty Individual Studies in Mathematics and Natural Sciences (MISMaP)

Thesis title:	*Optimization of CMS detector muon trigger in presence of RPC chambers noise.* (in Polish)
Supervisor:	dr hab. Grzegorz Wrochna
Title date:	31.05.2002

2006: Ph.D. in physics, University of Physics, Faculty of Physics,

Thesis title:	*Search for the heavy, neutral MSSM Higgs particles in the* $\mathrm{H/A} \rightarrow \tau\tau \rightarrow \mu + \mathrm{X}$ *channel in the CMS detector at the LHC*
Supervisor:	prof. dr hab. Jan Królikowski
Reviewers:	prof. dr hab. Jan Kalinowski prof dr hab. Elżbieta Richter-Wąs
Title date:	09.10.2006

3 Employment at scientific institutions

01.10.2002 – 30.09.2006	University of Warsaw, Faculty of Physics, doctoral studies
01.10.2006 – 31.01.2007	University of Warsaw, Faculty of Physics, technical employee
01.03.2007 – now	University of Warsaw, Faculty of Physics, assistant professor (adjunct), (on leave of absence 01.10.2007 – 31.08.2010)
01.10.2007 – 30.03.2009	Regina University, Regina, Canada, postdoc (based at CERN, Genewa)
01.04.2009 – 31.04.2009	Niels Bohr Institute, Copenhagen University, postdoc
17.07.2009 – 31.07.2010	LLR, Palaiseau, France, postdoc (based at CERN, Genewa)

4 Scientific biography

4.1 During preparation of master and Ph.D. theses

On fourth year of masters studies at the College of Inter-Faculty Individual Studies in Mathematics and Natural Sciences (MISMaP) I began cooperation with the Warsaw CMS [1] experiment group (later called here the Warsaw Group) consisting of scientists from Faculty of Physics, University of Warsaw, Sołtan Institute of Nuclear Studies and Warsaw University of Technology. My task was development and simulation of first level trigger based on muon RPC chambers (later called here PACT). The Warsaw Group was, and still is, fully responsible for its design, construction and operation. Results of my work were documented in my M.Sc. thesis [2], and included in the CMS experiment documentation as part of it's internal technical notes [3, 4, 5]. My contribution was an important step of PACT development. I have continued this activity during first years of my doctoral studies. At that time I was responsible for maintenance and development of PACT simulation computer code, made during my M.Sc. studies. I was also working on database containing information on topology of the system and its interconnections. I have made important contribution to test and launch of the PACT system, which took place in 2006 at CERN during first of the CMS detector tests with cosmic muons (Magnet Test and Cosmic Challenge, MTCC) [6]. During MTCC, for the first time, data was taken by a fully equipped slice of the CMS detector (in 2006 the detector was not yet complete, and its elements were still at the surface above final location). Tests and launch were therefore done with use of data from observation of cosmic muons, and artificial test signals injected into the system [7, 8, 9]. First level trigger is the initial stage of the triggering chain. Trigger items based on muons in final state make one of the most important signatures used in physics analyses at hadronic machines.

During doctoral studies I was working on development of high level trigger (HLT) for the CMS experiment, based on τ leptons identification [10]. Using Monte Carlo simulations I was developing and testing an algorithm used for identification of hadronic τ decays. This algorithms is a key element of Higgs boson searches in the $\mathrm{H} \to \tau\tau$ decay, where both taus decay hadronically. Implementation of this algorithm in C++ language within the CMS software framework was an important step towards realization of my scientific goal during preparation of my Ph.D. thesis. The thesis was devoted to estimation of heavy, neutral Minimal Supersymmetric Standard Model (MSSM) higgs bosons discovery reach of the CMS detector. I have been working on this algorithm during my three summer stays at the Paul Scherrer Institute (PSI), Villigen, Switzerland in 2003, 2004 and 2005.

In October, 2006 I have defended a Ph.D. thesis *"Search for the heavy, neutral MSSM Higgs particles in the* $H/A \to \tau\tau \to \mu + X$ *channel in the CMS detector at the LHC"*, at the Faculty of Physics, University of Warsaw. My results were included into Physical Technical Design Report (PTDR) [11], which was an important document of the CMS Collaboration showing its physical potential. This result was presented at many international conferences on behalf of the CMS Collaboration, in particular I have been presenting it at the *Physics at LHC 2006* conference [12].

After obtaining Ph.D title I have been employed at the Faculty of Physics, University of Warsaw, first as an technical employee, and later as assistant professor (adjunct).

4.2 After obtaining Ph.D. title and current scientific activity

From October 2007 to September 2010 I was a postdoc at three institutions: CERN (employed by Regina University, Regina Canada), Niels Bohr Institute, Copenhagen, Denmark, and Laboratoire Leprince Ringuet (LLR), Palaiseau, France (based at CERN).

In period 2008 – 2009 I have moved to another big experiment by the LHC – ATLAS [13]. At that time I was working on identification of hadronic τ decays. I made an important contribution into hadronic τ decays identification algorithm based on likelihood function [14, 15, 16]. During my work for ATLAS three types of hadronic τ identification algorithms were available: classic, based on rectangular cuts, based on Boosted Decision Trees (BDT), and based on likelihood functions. The likelihood based one was giving best performance at that time.

In parallel with τ identification algorithm development I was also engaged in work on trigger systems using hadronic tau decays signatures, where I made an important contribution to development of Data Quality Monitoring (DQM) [17, 18]. During LHC start up, in September 2008, I was a member of the ATLAS detector operation team, as a shifter in the ATLAS control room. I performed duty at high level trigger, data quality monitoring, and electromagnetic calorimeter control desks.

Since 2009 I am again a member of the CMS Collaboration, first as postdoctoral research fellow at LLR, France, later as adjunct at Faculty of Physics, University of Warsaw. At that time I have continued work on physical objects reconstruction, and come back to searches for the Higgs boson, this time within the Standard Model (SM). From 2009 to 2010 I was taking part in development of particle flow algorithms of event reconstruction [19, 20]. This innovative method has quickly became baseline method for physical objects reconstruction in the CMS experiment. Since 2009 my interest turn back to searches of Higgs boson in decay into two τ leptons, where one τ decays to muon and neutrino, and the other one decays hadronically. During summer of 2011 I have made one of first measurements of combined trigger item using decay of τ pair to muon, neutrinos and hadrons. This measurement was made using first 700 pb^{-1} of data collected at $\sqrt{\mathrm{s}} = 7$ TeV.

In the years 2009 – 2010 I made an optimization of the selection criteria in the analysis devoted to Vector Boson Fusion (VBF) production mode. Results of this work were frequently presented at the CMS Collaboration meetings. In the years 2011 – 2013 I have been developing background estimation methods aiming at the W+jet and QCD dijet processes. This work was part of HOMING PLUS/2010-2/5 Project, financed by the Foundation of Polish Science (FNP) *"Study of Standard Model processes with a jet identified as hadronically decaying tau and a muon in the final state, using the LHC data collected in 2010/2011 running period by the CMS experiment"*. Within the Project, with a master student, we were examining possibility of estimating the abovementioned backgrounds using weighted distributions obtained from control regions. The control regions were defined by a loosing τ identification criteria. The weights were calculated using the jet$\rightarrow \tau$ misidentification rate (so called fake rate). The method gave results comparable with ones obtained by other research groups, and was an important cross check of estimation of the W+jet and QCD dijet backgrounds making contribution to analysis which revealed positive signal in search for $\mathrm{H} \rightarrow \tau\tau$ decays [21].

From 2010 to 2014 I have presented results of the Higgs boson searches, obtained with my contribution on number of international conferences [22, 23, 24, 25].

Besides contribution to physical analyses, in years 2010 and 2011 I have been a member of the CMS detector control team. I have been a high level trigger operator ("HLT shifter") controlling HLT during routine data taking. In particular, in 2010, I have been honored to be in the control room team in the evening after second start up of the LHC. Unfortunately during my shift, the LHC control team did not manage to provide proton-proton collisions (at that time a full magnet cycle took few hours, which gave only a single try during one, eight hour, shift).

In parallel with experimental activity I have been active on the phenomenological field. In 2009 I was estimating τ decay structure functions in $\tau \rightarrow a_1\nu \rightarrow 3\pi\nu$ decays, using weighted decay angles distributions defined in publication [26]. This work was made in cooperation with prof. dr hab. Zbigniew Wąs as part of development of the TAUOLA program [27], and were documented as part of the Working Group on Radiative Corrections and Monte Carlo Generators for Low Energies report [28].

In 2010 I was a member of the *LHC Higgs Cross Section Working Group*, which consists of experimental (ATLAS and CMS Collaborations members) and theoretical physicists. I was working on estimation of cross section for production of Higgs bosons in MSSM model, making a contribution to the first report of the group [29].

In years 2011 – 2012, as a member of a research team lead by dr hab. Leszek Roszkowski, within project WELCOME/2010-3/1, financed by FNP. I was working on influence of the LHC Higgs and supersimmetric searches on constraints in the supersymmetric parameter space. My contribution was interpretation of the CMS experiment results in a way allowing for use of the Bayesian approach. The results of this work were published in [30].

Currently, from second half of 2014 I start up an analysis aiming at estimation of the spin and parity of the Higgs boson in the decay to two τ leptons. The quantum numbers of the particle with mass $m = 125$ GeV/c^2, observed by the ATLAS [31] and CMS [32] Collaborations, identified as a Higgs boson were analyzed in decays to intermediate bosons WW, ZZ and $\gamma\gamma$ [33, 34, 35, 36], with a result indicating state J^P 0^+, but a corresponding measurement was not yet made in a fermionic decay. I am a main investigator in a project (starting in January 2015) *"Decays to τ leptons – a tool for Higgs boson properties measurements by the CMS experiment at the LHC"* financed by the Polish National Science Center (NCN) in OPUS program. Together with preparations for Higgs boson properties measurement I take part in upgrade of the CMS detector. In the years 2013 – 2014, during the LHC shutdown, the are ongoing intensive upgrade works of the detectors and LHC itself. As a main investigator in a project *"New muon trigger system of the Compact*

Muon Solenoid (stage I, 2014-2016)" I work on algorithms of a new first level trigger system, using input signal from all muon detectors.

5 Presentation of the scientific achievement

in accordance with Polish regulation Art 16. ust. 2 Ustawy z dnia 14 marca 2003 roku „O stopniach naukowych i tytule naukowym oraz o stopniach i tytule w zakresie sztuki" (Dz.U nr 65 poz. 595 z późniejszymi zmianami).

As the scientific achievement I present a monograph entitled:

Selected aspects of Standard Model Higgs boson searches at the CMS experiment by the LHC

released (in Polish) by the University of Warsaw Publishing, Warsaw 2014, ISBN 978-83-235-1708-5, of which I am a sole author.

The monograph presents aspects of searches for a Higgs boson particle appearing in the Standard Model (SM) as a consequence of the Brout-Englert-Higgs (BEH) spontaneous symmetry breaking mechanism.

So far my scientific work was concentrated around different aspects of Higgs boson searches in the decay to two τ leptons, which is reflected by extended content of the Chapter four devoted to this decay. My work on trigger systems, and participation in data taking states also a contribution to analyses on the other decay channels. Therefore the monograph contains description of all main search channels. A second reason for including other decay modes is fact that identification of a new particle as the SM Higgs boson requires complex analysis, taking into account all accessible channels, and all properties that can be estimated, in particular couplings to all SM particles and its quantum numbers.

Monograph begins with a concise historical review presenting evolution of Higgs boson mass limits stopped by discovery of the particle announced on 4 July, 2012 by ATLAS [31] and CMS [32] Collaborations. First chapter shortly reminds basics of the Brout-Englert-Higgs mechanism. In this chapter I present values of the Higgs boson branching ratios to SM particles, and main production modes at the LHC. Since the Higgs boson coupling is proportional to a particle mass, Higgs boson preferably decays to heaviest accessible particles. For $m_{\mathrm{H}} < 2 \cdot m_{\mathrm{W}}$, where m_{W} is a W boson mass, decays into b quark pairs dominate, later there is a sharp rise of $\mathrm{H} \to \mathrm{WW}$ and $\mathrm{H} \to \mathrm{ZZ}$ decay fractions. Finally after crossing a threshold for decay to top quarks pair, $\mathrm{H} \to \mathrm{t\bar{t}}$ decay mode becomes also important. The list of main production channels of the Higgs boson at the LHC is determined by types of particles appearing in the initial state: gluons and quarks. In this situation the dominating production mode is gluon fusion (ggH): $\mathrm{gg} \to \mathrm{H}$, next there is vector boson fusion (VBF), where vector bosons are emitted from initial state quarks. Next process is *Higgs-strahlung* (VH), where a Higgs boson is emitted from intermediate boson propagator appearing in annihilation of initial state quarks. The last production mode is associated production with a pair of top quarks (ttH). The decay pattern only with conjunction with production mode determines accessible search channels of new particles. The most frequent decay, in the intermediate Higgs boson mass range, $\mathrm{H} \to \mathrm{b\bar{b}}$ is extremely difficult at hadron colliders due to overwhelming background of QCD dijets, that could be misidentified as b quark jets. Only in connection with particles from production final state, in particular leptons, one could think about using this channel for a Higgs boson searches at hadronic collider. Such additional identification handles are provided in particular by the VH process, where leptonic decays of associated W or Z boson provide a very strong signature.

In a similar way, the VBF process allows for an efficient signal selection, due to presence of additional quarks scattered from initial to final state. Those quarks give rise to tagging jets, which could be required in analyses devoted to this production mode.

Chapter two shortly presents the CMS detector and particle reconstruction and identification methods used in analyses described in following chapters. In particular particle flow algorithm has been described in some detail. Chapter four presents statistical methods used for estimation of exclusion limits, in case of lack of signal, or statistical significance in case of positive observation of expected signal. Basic statistical conventions, like "5σ level", or "p-value" are defined in this chapter. Also the strength parameter μ is defined there.

Following chapters, from four to eight describe Higgs boson searches in particular channels, respectively: $\mathrm{H} \to \tau\tau$, $\mathrm{H} \to \mathrm{b\bar{b}}$, $\mathrm{H} \to \mathrm{ZZ} \to 4\mathrm{l}$, $\mathrm{H} \to \mathrm{WW} \to 2\mathrm{l}2\nu$, $\mathrm{H} \to \gamma\gamma$.

Searches of the Higgs boson in the $\mathrm{H} \to \tau\tau$ decay are particularly interesting, since it is a second, ordered in branching fraction, decay into fermions. Given extreme difficulty in using the decay to b quark pair, the $\tau\tau$ channel was expected to give a first direct observation of Higgs boson coupling to fermions. ATLAS and CMS Collaborations have published results of searches in this channel, based on data collected in period 2011 – 2012. Both experiments have observed signal like excess of events on the level of 4.1σ [37] (ATLAS) and 3.2σ [21] (CMS), for $m_{\mathrm{H}} = 125$ GeV/c^2. Both Collaborations observe excess with statistical significance below discovery threshold of 5σ, but given very strong signal in $\mathrm{H} \to \mathrm{ZZ}$ [38, 35] channel, this excess is considered a very promising $\mathrm{H}\tau\tau$ coupling evidence. The CMS result is based on analysis of 4.9 fb^{-1} of data collected at the energy of $\sqrt{s}$=7 TeV, and 19.7 fb^{-1} at $\sqrt{s}$=8 TeV, which is the full dataset collected in the years 2011 – 2012. In the monograph I have presented main aspects of searches in $\mathrm{H} \to \tau\tau$ channel. I have restricted myself to analyses aiming at gluon fusion and VBF production modes, to which I have contributed.

The $\mathrm{H} \to \mathrm{b\bar{b}}$ is a next, after $\tau\tau$, fermionic Higgs boson decay accessible at the LHC. Eventual observation of this decay would directly confirm Higgs coupling to quarks (indirectly this coupling is probed by its contribution to production modes, like in $\mathrm{gg} \to \mathrm{H}$ mode). This channel however is extremely difficult, due to huge background of dijet events originating from fragmentation of not only b quarks, but also light quarks and gluons. ATLAS and CMS Collaborations have published results of searches in this channel based on all data collected during first phase of LHC in the years 2011 – 2012. The

ATLAS Collaboration did not observe signal, and reported an exclusion limit of 1.4 for $m_{\mathrm{H}} = 125$ GeV/c^2 [39]. The analysis made by the CMS Collaboration shown presence of signal like excess with statistical significance of 2.1σ for $m_{\mathrm{H}} = 125$ GeV/c^2 with signal strength parameter $\mu = 1.0 \pm 0.5$ [40]. This result agrees with expectations for a SM Higgs boson. I present main aspects of searches in $\mathrm{H} \to \mathrm{b\bar{b}}$, which detail can be found in publication [40].

The $\mathrm{H} \to \mathrm{ZZ} \to 4\mathrm{e}/4\mu/2\mathrm{e}2\mu$ decay, called a "golden", provided very clean signal, that could be seen with a bare eye on mass distributions of four charged leptons selected by analyses made by the ATLAS and CMS Collaborations. Both Collaborations have observed signal indications already after analyzing first 5 fb^{-1} of data [41, 42]. Finally the ATLAS Collaboration has observed excess with statistical significance on the level of 6.6σ, with mass of $m_{4\mathrm{l}} = 124.51 \pm 0.52(stat) \pm 0.06(syst)$ GeV/c^2 [38]. Analogous analysis made by the CMS Collaboration shown signal with mass of $m_{4\mathrm{l}} = 125.6 \pm 0.4(stat.) \pm 0.2(syst.)$ GeV/c^2, with statistical significance of 6.8σ [35]. In monograph I have sketched strategy of searches in $\mathrm{H} \to \mathrm{ZZ} \to 4\mathrm{e}/4\mu/2\mathrm{e}2\mu$ channel realized in analysis documented in publication [35].

The Higgs boson decay to pair of W bosons has relatively large branching ratio. Already for $m_{\mathrm{H}} > 115$ GeV/c^2 this is second, after decay to b quarks, decay channel. Unfortunately this is quite difficult channel, since 44% of WW pairs decay to fully hadronic final state, extremely difficult to select among multi jet background. The channel, which provides sufficiently strong signature, is decay to light leptons: electron or muon and neutrinos, appearing only in 4.5% events. Analysis of data collected in the years 2011 – 2012 by both ATLAS and CMS experiments, shown signal like excess compatible with SM Higgs boson expectations. Excess observed by the ATLAS Collaboration has statistical significance of 3.8σ [43], while the one observed by the CMS has 4.3σ [34]. The chapter devoted to this channel shows elements of the analysis documented in publication [34].

Decay to two photons, was seen as one of two, besides the "golden" four lepton one channel providing early discovery, which indeed happened. The ATLAS and CMS Collaborations have observed signal like excess compatible with the SM Higgs boson expectations. Analysis of data collected by the ATLAS experiment shown a presence of resonance in the two photon decay with mass $m_{\gamma\gamma} = 125.98 \pm 0.42(\mathrm{stat}) \pm 0.28(\mathrm{syst})$ GeV/c^2 [38]. Statistical significance of this observation was 7.4σ [44]. Similar analysis made by the CMS Collaboration revealed a peak in diphoton mass distribution for $m_{\gamma\gamma} = 124.70 \pm 0.31(\mathrm{stat.}) \pm 0.15(\mathrm{syst.})$ GeV/c^2, with a statistical significance of 5.7σ [36]. In monograph I describe basic aspects of searches in $\mathrm{H} \to \gamma\gamma$ channel, which details documented in publication [36].

At the beginning of each chapter I recall, already known, results of searches published by the ATLAS and CMS Collaborations, next I present strategy, selections, background estimation methods and systematic errors considered in described analysis. Each chapter is finished with report on search results.

The last two chapters present results for mass and couplings study on the new particle, based on combination of results of analyses described in previous chapters. The conclusions contains projections on precision that could be achieved for SM Higgs boson at the LHC. After period of searches for the Higgs boson, which started in nineties of XX century, and ended on 4 July, 2012 a era of precise properties analysis has begun.

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