Załącznik nr 3

Summary of Professional Accomplishments

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1. Personal details

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2. Diplomas and academic degrees

MSc	2001 - University of Mining and Metallurgy, Krakow Department of Physics and Nuclear Techniques
PhD	2004 - University of Mining and Metallurgy, Krakow Department of Physics and Nuclear Techniques thesis „***Measurement of the electron structure function at LEP2 energies***" (completed with distinction) supervisor: prof. Bogdan Muryn

3. Employment record

2004 - 2005	University of Science and Technology Department of Physics and Nuclear Technique High Energy Physics Experiment Group assistant
2005 - 2007	University of Glasgow School of Physics and Astronomy Particle Physics Experiment Group Research Assitant
2007 - 2009	University of Glasgow School of Physics and Astronomy Particle Physics Experiment Group Research Associate (core staff)
2009 - 2010	CERN (*Organisation* Européenne pour la Recherche Nucléaire) PH-LHCb Long Term Attachment Research Associate (University of Glasgow)
2011 - present	AGH - University of Science and Technology Department of Physics and Applied Computer Science Particle Interactions and Detection Techniques Group assistant professor

4. Scientific achievement as grounds for the habilitation procedure

4.a Title

Tomasz Szumlak, „*Performance of the LHCb Vertex Locator and the measurement of the forward-backward asymmetry in $B_d \rightarrow K^{*0}(892)\mu^+\mu^-$ decay channel as a probe of New Physics*", Publisher JAK, Krakow 2013, ISBN 978-83-934620-9-4

4.b Description of the achievement as grounds for the habilitation procedure

Introduction

The LHCb experiment [1], currently operating at the LHC collider [2] at CERN, is dedicated to searching for New Physics effects in the heavy flavour quark sector and precise measurements of CP violation and rare $B_{d(s)}$ and $D^{(*)}$ meson decays. These topics are at the centre of the modern high energy particle physics. The LHCb experiment was especially designed to tackle the problem of baryon asymmetry which manifests itself as a local excess of matter over antimatter. This local matter antimatter asymmetry, observed experimentally, cannot be explained by the Standard Model, which constitute the theoretical framework of the high energy physics and is used to describe the fundamental matter constituents and their interactions. Astronomical observations confirm that also on the larger scale there is no macroscopic amounts of antimatter present in the Universe. These studies allow to estimate the ratio, ε, between the baryon matter density, ρ_B, and photon density (based on the cosmic background radiation), ρ_γ, to be of order of $\varepsilon \approx 10^{-10}$.

Theoretical description of the baryogenesis was first proposed by Sakharov in his famous paper published in 1967 in a form of three postulates [3]. The first one assumes that there is a process (or processes) that violates the baryon number conservation law. The second assumes that both charge, C, and combined charge-parity, CP, symmetries are violated. Finally, the last postulate states that the baryogenesis should happen away from the thermodynamical equilibrium. In principle the SM can accommodate all of these requirements, i.e., the electro-weak sector of this model violates both C and P symmetries as well as features CP asymmetry. However, the theoretical calculations, based on the SM, predict baryon asymmetry that is orders of magnitude smaller than that presently observed.

This fact gives a very strong motivation to searching for new processes beyond the SM. In order to reveal this New Physics phenomena an intensive experimental work enhanced by the appropriate theory guidance is needed. It is a general believe that New Physics beyond the SM must have flavour structure of some sort. This structure can be probed directly by the ATLAS [4] and CMS [5] or indirectly by the LHCb via studying CP-violation and rare decays that can be described by quark transitions involving higher order loop diagrams. These direct searches performed by both ATLAS and CMS experiments led to Higgs boson discovery [6, 7] which was the only missing particle present in the SM. On the other hand the indirect approach employed by the LHCb can be considered as complementary one, with respect to the ATLAS and CMS physics programmes. Very precise measurements that are being performed by the LHCb are sensitive to higher order virtual processes, that can proceed by exchange of new heavy particles. This puts the LHCb in an unique place of being, potentially, the only experiment able to detect New Physics phenomena, via indirect measurements beyond the energy frontier.

Physics measurements performed by the LHCb experiment are very subtle, thus, it is necessary to use very efficient and extremely precise tracking system able to reconstruct charged particle trajectories on-the-fly. Tracks that are reconstructed in on-line mode are then employed to provide complex topological information essential for the High Level Trigger system. In order to attain these goals the LHCb spectrometer was equipped with the vertex detector VELO (VErtex LOcator). The VELO performs precise measurements of charged tracks close to the beams crossing point, which are used to reconstruct the primary (proton-proton interaction) and secondary vertices (long-lived particle vertices). The latter, also known as displaced vertices, constitute the most essential signature of heavy flavour meson decay events. Measurements provided by the VELO are also critical for determination of the geometrical impact parameter and proper lifetime of $B_{d(s)}$ and $D^{(*)}$ mesons. These variables, in turn, are critical for background discrimination and used in most of the selection algorithms in the LHCb.

The presented work contains description of selected scientific projects that have been performed by me between 2005 and 2013 while being a member of the LHCb experiment. The paper is split into tree chapters describing subsequent stages of collision data processing and analysis. The discussion spans from the electronic signal conditioning by the front-end chips, hits and tracks reconstruction to physics analysis. This material is largely related to the VELO detector which reflects both my direct contribution to commissioning and running this system and its vital role in my physics analysis. All results that are discussed in the following text represent my genuine contribution to the LHCb experiment.

Raw data processing emulation and charged particles position reconstruction for the silicon micro-strip vertex detector VELO

Charged particle trajectories reconstruction procedure depends critically on the quality of their position reconstruction performed by the LHCb tracking system. For the VELO this is done by especially designed electronic acquisition boards Tell1[1] [8], that make a vital part of the LHCb trigger system [9]. Tell1 boards process the analogue signals that are read out from VELO sensors by the electronic front-end chips, perform their digitization and processing in order to detect hits, produced by charged particles that deposit charge within the active material, and robustly discriminate the noise. The digital signal processing is done by a complex chain of algorithms, implemented in the low level machine language HDL (Hardware Description Language), and run by FPGA[2] processors on the Tell1 boards. Once the hit detection is finished the clusterisation procedure is executed that associates hits associated with a single particle into objects called clusters, that represents the charge distribution deposited by this particle within a silicon sensor. All reconstructed clusters (for a single event) are subsequently encoded into a data structure called the raw bank. This bank constitute a fragment of registered event and is sent for further processing to the High Level Trigger (HLT).

The RawBank represents the final step of the local data analysis of the data coming directly from the hardware systems of the LHCb spectrometer. The content of this bank cannot be changed or modified. This sets extremely high requirements for the digital processing algorithms (concerning their efficiency and robustness) that are used to detect the hits and create the cluster bank. In order to assert these features a specialised suite of software tools and procedures are needed for automatic calibration, configuration and monitoring of the processing algorithms performance during the collision data taking,

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[1] Trigger ELectronic L1
[2] Field Programmable Gate Aarray

I came up with an idea, that was accepted by the Collaboration, of creating a software platform implementing the full emulation of the Tell1 digital processing of charged particle hits reconstruction. This software is based on the official framework used by the LHCb experiment (called Gaudi) and is able to process the collision data collected by the VELO detector. The cluster bank produced by the emulator software is identical to that created by the Tell1 board and allows for their direct comparison. This in turn can be used to check the hit selection algorithms performance, diagnose problems and test new enhanced versions of the processing suite. The final version of this project was called VETRA [10] and was designed, implemented and commissioned under my supervision. Thanks to the VETRA software it was possible to complete a rapid calibration of the VELO detector during the first tests of the LHCb detector using muon beams induced by the LHC proton beam. In fact the VELO was the very first detector that successfully detected charged particles produced in the LHC collider [11].

The VETRA project represents a novel approach to hardware emulation, calibration and monitoring of the acquisition system applied for a high energy physics experiment. The emulation has been completely integrated into the official software framework of the LHCb experiment. It is fully capable of processing the collision and noise data collected by the VELO detector and producing the data that can be used to reconstruct tracks. The VETRA software is an essential tool that allows daily operation of the VELO during the data taking period. The functionality of the emulation platform has been enhanced accordingly in order to support operation of all sub-systems of the LHCb spectrometer that use silicon micro-strip detectors (VELO, TT – Triger Tracker oraz T – Tracking stations).

Measurement of the spatial resolution of the LHCb vertex detektor VELO

The spatial intrinsic resolution is a fundamental characteristic for each silicon position sensing device that determines the precision of a particle position reconstruction. In case of the LHCb experiment a unique approach was used (for a collider type experiment) where silicon sensors of the vertex detector are perpendicular to colliding proton beams. Also, the first active elements of the VELO detector are as close as 8 mm to the particle beams. Since the precision of physics measurements is the main concern for indirect searches for New Physics the excellent tracking and vertexing capabilities are essential for the LHCb spectrometer. This in turn, asserts very high resolution for both the impact parameter and proper lifetime variables, that are essential for trigger performance. The highest possible spatial resolution has critical impact on all of these quantities.

This position resolution is provided by an appropriate segmentation applied to a silicon sensor. For instance each R-type VELO sensor is divided into four 45 degrees sectors each of which has 512 strips. The width of these strips is commonly called pitch. In the case of silicon devices with a single threshold binary readout their intrinsic resolution[3] depends solely on the pitch. This, assuming that the readout implant is at the centre of the strip, is can be expressed as:

$$\sigma^2 = \frac{P^2}{12}$$

where: P is the local pitch. In such case the spatial resolution depends solely on the sensor segmentation. A significant improvement in resolution can be achieved by using full analogue sensor readout. In this case the charge deposited by a traversing particle can be registered on more than one strip and, additionally, measured signals are proportional to the deposited energy. This may result in the production of a multi-strip cluster which more accurately represent charge cloud produced by the

[3] Called binary resolution

passing particle. In particular the cloud barycentre (or centre of gravity) can be estimated using inter-strip interpolation algorithm.

The specific VELO geometry and significant number of sensors that are distributed over a large distance from the crossing point (the length of the detector is close to 1 m) make very difficult to evaluate spatial resolution for the LHCb vertex detector. Although all VELO sensors are in principle identical (with respect to their physical properties) the measured effective spatial resolution may vary dramatically depending on the z-coordinate of a given sensor. Additionally, significant differences in resolution are expected across each sensor which is a consequence of the floating strip pitch (the pitch is a continues function of the radius) as well as the fact that both particle flux density per readout channel (i.e., sensor occupancy) and track angle distribution can change significantly from sensor to sensor. These effects must be studied in detail and understood in order to determine an appropriate parameterisation that would be used to describe the spatial resolution for the VELO.

As a member of the VELO project I was directly responsible for the following tasks: design and implementation of the clusterisation algorithm, charge sharing model definition (based on test-beam measurements) and finally estimate of a single hit position precision that corresponds to the intrinsic spatial resolution at a given point. The most important results, related to this work, are the specialised software used to create, so called, "measurements"[4] that is the first step of the pattern recognition procedure and uncertainty for a single hit position measurement.

.In the case of the VELO the spatial resolution, that defines a single hit precision, is a complicated function that depends on two parameters: the strip pitch and track projected angle. The latter must be calculated for each track using the local strip geometry. In Figure 1 the spatial resolution, measured for the collision data, is shown as a function of the projected angle. In Figure 2 the same quantity is presented as a function of the strip pitch.

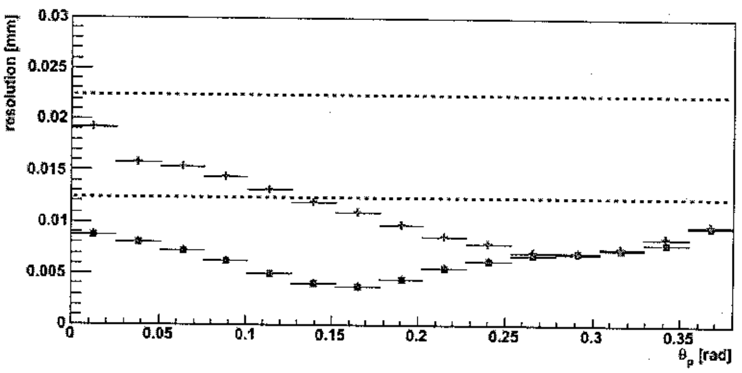

Figure. 1. Spatial resolution evaluated using a simulated data sample presented as a function of the projected angle for selected sensor pitch bins – red points: pitch ∈ (0.04, 0.044) mm and blue points pitch ∈ (0.08, 0.084) mm. The corresponding broken lines represent the mean binary resolution for both pitch intervals. The optimal projected angle, for which measured resolution is the best, depends strongly on the sensor pitch..

Measured VELO resolution is much better than the binary one (defined by the sensor segmentation). The resolution, obtained for the smallest pitch and optimal projected angle, is close to 4 μm and is the best in the LHC. This, in turn, asserts also the best resolutions for the primary and secondary vertices, impact parameter and proper lifetime.

[4] The measurement is a complicated object containing the following: estimated position of a reconstructed particle and its uncertainty as well as topological information related to a channel (or channels) where the particle was registered.

Both the VELO resolution measurement and appropriate uncertainty parameterisation for a single hit, based on this studies, are essential for the successful VELO operation. Excellent position precision obtained by the LHCb vertex detector allows to use it as a essential part of the tracking system. The high quality data produced by this detector and critical for the trigger system and physics selection algorithms.

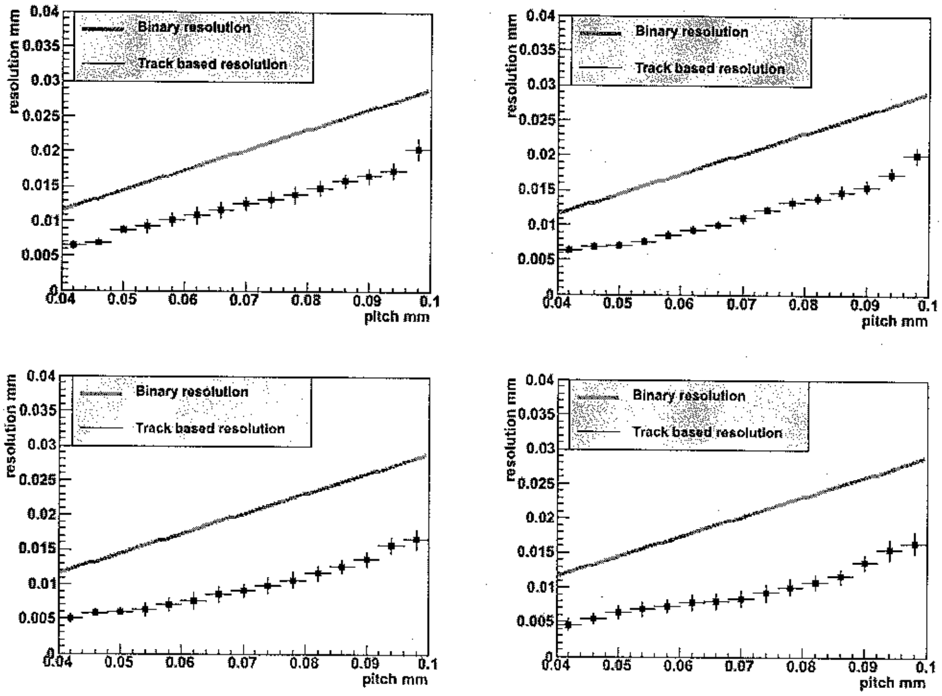

Figure. 2. Spatial resolution evaluated using the collision data given as a function of the sensor strip pitch for a selected projected angle bins – top left: $\theta_p \in (0.0, 0.035)$ rad , top right $\theta_p \in (0.035, 0.07)$ rad, bottom left: $\theta_p \in (0.10, 0.14)$ rad and bottom right $\theta_p \in (0.21, 0.3)$ rad. Solid line represents the binary resolution.

Search for New Physics using the forward-backward asymmetry measured for the rare decay $B_d \to K^{*0}(892)\mu^+\mu^-$

Search for New Physics (NP) signals beyond the Standard Model is the main mission of the LHCb experiment. One of the "golden channels" considered by the LHCb is the rare decay mode $B_d \to K^{*0}\mu^+\mu^-$ for which both sufficiently accurate theoretical calculations and clean experimental measurements are possible. This decay is especially regarded as one of the most promising processes for revealing NP signatures. On the quark level this decay can be described as $b \to s$ transition that cannot be described by tree diagrams within the SM theoretical framework. Instead it can only proceed via higher order loop diagrams that represent the exchange of neutral currents (Flavour Changing Neutral Currents).

Extensive phenomenological studies of the $B_d \to K^{*0}\mu^+\mu^-$ decay channel provided a number of observables that can be used by experiments to search for NP signals. Especially interesting, due to reduced hadronic uncertainties, is the forward-backward asymmetry (A_{FB}). Theoretical interpretation of this measurement is based on an assumption that the decay can be described by the effective weak Hamiltonian that, in turn, can be expressed as a linear combination of terms proportional to appropriate CKM matrix elements and Wilson coefficients [12]. The fundamental idea behind the effective theory is related to the fact that decaying heavy mesons (B, D, etc.) may be represented by point-like effective diagrams rather than the ones with $W^{\pm}$ and Z^0-propagators that are suitable to describe processes at very short distance scale $O(M_{W^{\pm},Z^0})$. In that manner the long- and short-distance effects[5] can be separated, in particular, all short-distance contributions (or hard momentum processes) are integrated out and represented by the corresponding Wilson Coefficients. Thus, if new heavy particles beyond the MS exist their presence can be detected via modified Wilson Coefficients. Potentially, each quantity that can be expressed in terms of these coefficients should be sensitive to NP effects. In practice the contribution from long-distance processes cannot be completely neglected and play an important role. All non-perturbative contributions have large theoretical uncertainties which limits the sensitivity of such observables to NP. With this respect the forward-backward asymmetry is unique, since, its determination is based on kinematical variables of muons observed in the final state. Thanks to this the pollution coming from the long-distance effects is very small in case of the A_{FB}.

Forward-backward charge asymmetry can be expressed as follow:

$$\frac{dA_{FB}}{dq_{\mu\mu}^2} = \frac{1}{\mathcal{N}} \int_{\cos(\theta_l)=-1}^{\cos(\theta_l)=1} sgn[\cos(\theta_l)] \frac{d^2\Gamma}{dq_{\mu\mu}^2 dcos(\theta_l)} d\cos(\theta_l)$$

where: $q_{\mu\mu}^2$ is di-muon invariant mass squared, Γ represents the decay rate, θ_l is the angle between the momentum vector of μ^- (μ^+), determined in the di-muon rest frame, and the $\bar{B}_d^0$ (B_d^0) momentum vector measured in this frame, finally $\mathcal{N}$ is the total number of observed signal events.

From the experimental point of view the asymmetry has a very simple interpretations – it represents the difference between the number of, so called, forward and backward events determined as a function of the di-muon invariant mass squared - events are counted in the di-muon rest frame. An event is tagged as forward (backward) if $\theta_l \leq \pi/2$ ($\theta_l > \pi/2$). Hence, in order to make this measurement it is enough to reconstruct precisely four-momenta of both muons and perform an appropriate counting. The formula describing the forward-backward asymmetry can be rewritten in terms of the Wilson Coefficients as follow:

$$\frac{dA_{FB}}{dq_{\mu\mu}^2} \propto \left(1 - \frac{q_{\mu\mu}^2}{m_b^2}\right)^2 \frac{q_{\mu\mu}^2}{m_b^2} \mathcal{C}_{10} \left(\mathcal{C}_9 + 2\left(\frac{q_{\mu\mu}^2}{m_b^2}\right)^{-1} \mathcal{C}_7\right)$$

where: m_b is the mass of beauty quark, $\mathcal{C}_7$, $\mathcal{C}_9$ and $\mathcal{C}_{10}$ are appropriate Wilson Coefficients. Hence, if NP effects modify the value of these coefficients the shape of the asymmetry function will also change accordingly [13].

A measurement of the A_{FB} using binned method was performed by the LHCb Collaboration with a data sample corresponding to $1\,fb^{-1}$ of the collision data taken in 2011 [14]. Because of the limited statistics (the used sample contained approximately 900 signal events) obtained results have significant uncertainties. Specifically the obtained value of the zero-crossing point of the forward-backward asymmetry is $q_0^2 = 4.9 \pm 0.9\ GeV^2/c^4$, where the uncertainty contains both statistical and systematic components. This value is consistent with the SM theoretical predictions, $(q_0^2)_{Th}$, which varies from $4.09^{+0.16}_{-0.13}$ to $4.36^{+0.33}_{-0.31}$ depending on the calculation technique. The small number of events does not allow to compare the measured shape of the asymmetry with the theoretical curves.

An alternative and novel approach to measurement of the forward-backward asymmetry was proposed by the Glasgow group of the LHCb Collaboration. This new technique was based on the un-

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[5] These terms refer to characteristic distances intrinsically related to given interaction processes and should be interpret within the context of the uncertainty principle. For instance weak interactions are treated as short-distance processes.

binned non-parametric kernel density estimation method developed originally by Parzen [15]. The kernel method can potentially be much more sensitive with respect to the "classical" binned one.

As a member of the Glasgow group at that time I took an active role in developing this method and adapting it to the specifics of the LHCb experiment. In particular I was a co-supervisor of two PhD projects related to the forward-backward asymmetry measurement. An appropriate selection algorithm (cut-based) has been defined and tested using large Monte-Carlo samples, containing both signal and background events. Detailed optimisation procedure for the kernel bandwidth parameter h [16] has also been created. I showed that the bandwidth optimisation is a critical part of the asymmetry reconstruction. The results obtained with this method are shown in Figure 3.

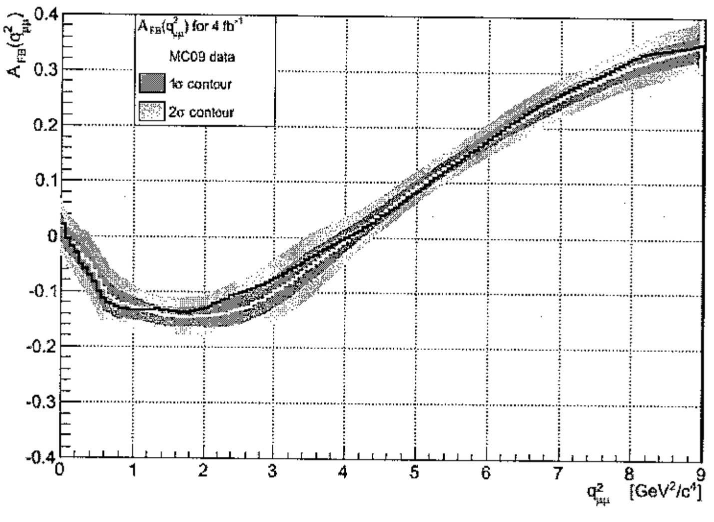

Figure. 3. Forward-backward asymmetry reconstructed using a data set corresponding to integrated luminosity of $4\,fb^{-1}$ (depicted using the blue line). White line represent estimate of the true asymmetry that was obtain using a large number of data sets (as described in the text) and green and yellow bands represent its uncertainty. In both cases asymmetry curve representing one individual data set is reasonably close to the true one, i.e., is contained within the 2σ band.

The main feature of the obtained result, using the kernel method, is that the reconstructed asymmetry in the decay $B_d \to K^{*0}(892)\mu^+\mu^-$ is a continuous curve. It allows to compare directly the experimental measurement and theoretical predictions based on different New Physics models. In case of the kernel method the sensitivity to changes of the shape of the measured asymmetry, induced by the modified Wilson Coefficients, is potentially much better than the one obtained using the binned approach. Also, for the continuous curve the crossing point of the asymmetry can be obtained directly, whereas for the binned distribution this requires interpolation between appropriate bins, which can increase the uncertainty of the measurement and bias its value. These effects are not present for the kernel method. The performed studies show that if NP processes modify the Wilson Coefficients and change the shape of the forward-backward asymmetry the un-binned kernel method can be considered a perfect tool to discover this.

Summary

In the paper „***Performance of the LHCb Vertex Locator and the measurement of the forward-backward asymmetry in*** $B_d \to K^{*0}(892)\mu^+\mu^-$ ***decay channel as a probe of New Physics***" I discussed tree distinctive but correlated scientific projects which were performed by me during my work for the LHCb Collaboration.

The first one was related to the design and implementation of the software platform for the Tell1 electronic acquisition board emulation and performance monitoring. As a result of this work a specialised application VETRA has been commissioned. This makes a vital part of the VELO software that is used to run the LHCb vertex detector VELO and other sub-systems that employ silicon micro-strip devices. The VETRA is used, among others, to rapid calibration of the processing algorithms run on the Tell1 board and for diagnostic of the VELO detector.

Next project was dedicated to the study of the VELO hit reconstruction and its spatial resolution. In course of work an algorithm for particle position measurement has been provided. Also, detailed studies of the resolution as a function of the strip pitch and track projected angle have been performed reviling its complex nature. In the case of the VELO detector the correct determination of the spatial resolution is very difficult. A detailed parameterisation of this quantity is of the paramount importance for the trajectory fitting, which in turn, is used for the momentum measurement.

The final project was related to the forward-backward charge asymmetry measured using the rare beauty decay $B_d \to K^{*0}(892)\mu^+\mu^-$. In the paper I presented a novel approach for the asymmetry reconstruction based on the un-binned non-parametric kernel density estimation technique. I took a leading role (as a member of the Glasgow LHCb group) in defining and tuning the selection algorithm and preparing the optimisation procedure for the kernel bandwidth parameter. The kernel method allows to reconstruct the asymmetry as a continuous curve what makes this measurement very sensitive to any change in shape induced by New Physics effects. Studies using large Monte-Carlo samples proved that the method is feasible to perform the measurement using the LHCb data. It was also estimated that with the full sample of events from both Run I and Run II it will be possible to settle the problem of agreement of the measured asymmetry with the one obtained from the SM predictions.

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5. The summary of research work

5.1 Period before receiving the PhD title

I started my scientific work in year 2000 during preparation of my master of science project describing photon-photon interactions, leading to production of the hadronic system in the final state, observed by the DELPHI experiment at the LEP collider. I performed the analysis of data sample collected during the Run II of the DELPHI detector. The phenomenological description of such processes assume that the interacting electrons emit photons which subsequently collide and produce the final hadronic system. I used, so called, single tag technique to select events containing one scattered electron with high transverse momentum and hadronic particles with sufficient invariant mass (larger than 3 $\frac{GeV}{c^2}$). Since, the main signature of the two photon events contained an electron detected by the STIC (The Small angle TIle Calorimeter) detector I also took part in studies related to efficiency measurement of this detector. The results of this studies were used in various papers prepared by the Two Photon Physics working group of the DELPHI experiment.

After completing my MSc I started my PhD project, also with the Krakow group of the DELPHI experiment. The main topic of my thesis was the Electron Structure Function (ESF) measurement using the photon-photon interactions. This novel technique was proposed and developed by two theorists from the Jagiellonian University in Krakow (Wojciech Słomiński and Jerzy Szwed). It is an alternative approach with respect to the Photon Structure Function (PSF). The analysis met with a lot of interest and attention from physicists involved in studying the photon-photon interaction. The main advantage of the ESF method is that the photon-photon cross section measurement can be performed as a function of a new scaling variable, z, which can be determined using the kinematical properties of the high-p_T electron observed in the final state (tagged electron). This makes the ESF technique much less model depended. In particularly, it is possible to avoid using the complicated statistical reconstruction method (unfolding) that needs to be employed in the case of PSF to recover the mass distribution of the hadronic final state.

As a member of the Krakow group from the AGH-UST that was a part of the DELPHI Two Photon Physics working group I was responsible for preparing the complete analysis of the data taken during the Run II. I prepared and tuned a selection algorithm for single tagged photon-photon events, performed detailed analysis of the detection efficiency for these events using large Monte-Carlo samples. The preliminary results of this analysis were presented on large international conferences and published [D1] (note, this enumeration is taken from the list of publication included in appendix 5). I defended my PhD thesis in 2004 with distinction.

Apart from the ESF analysis I also took part in analysis related to production of hadronic resonance state η_c. I was also delegated to presents the analysis on ICHEP 2002 conferences in Amsterdam. The results were published both as conference proceedings and DELPHI paper [A3, B2].

5.2 Period after receiving the PhD title

After defending my PhD thesis I was employed by the AGH University and at the same time I was accepted as a member of the Krakow group contributing to the LHCb experiment. My main involvement in the work of this new group was related to High Level Trigger software preparation.

In 2005 I applied for a post-doc position with the Glasgow University LHCb group and was accepted. The Glasgow group of the LHCb experiment was primarily involved in construction of the LHCb vertex locator (VELO) silicon micro-strip detector. My first project was related to the design and implementation of the VELO silicon sensors response simulation application for the LHCb. This project was considerably large and complicated and I split it into a number of steps. The first stage was devoted to the application's general architecture that had to be compatible with the official experiment software framework Gaudi. One of the most critical tasks of this step of the design was to define and test the appropriate data model. This model had to comply with the requirements imposed by the framework and at the same time describe the physical objects with sufficient details. Results of this work were published in an experimental paper [D2] and discussed in working meetings during the collaboration workshops. After my work was approved by the Collaboration I prepared and implemented the physics part of the simulation, including the spill-over effect (superposition of signals coming from different events and registered on the same readout channels) as well as emulation of the front-end chip. These results have been published later in the LHCb performance paper [C6].

At the same time I finished my data analysis regarding the ESF. I was invited to HEP 2005 conference to give a summary plenary talk on both photon and electron structure functions measurement performed at LEP. I presented the final results of these analyses for the DELPHI, OPAL and ALEPH experiments.

After completing my work with the simulation software (2006) I became a coordinator of the VELO hit reconstruction project. This work was very important for the success of the VELO detector as the tracking device. I designed and implemented a number of software tools for particle position reconstruction, uncertainty assignment and data preparation for the pattern recognition. More detailed description of the results in given in Chapter 3 of my paper „***Performance of the LHCb Vertex Locator and the measurement of the forward-backward asymmetry in*** $B_d \to K^{*0}(892)\mu^+\mu^-$ ***decay channel as a probe of New Physics***". I also published appropriate experimental notes [D3, D4].

In 2007 I was proposed an extension to my contract and advancement to position of Research Associate. In the same time I proposed to create a specialised software platform for the full emulation of the electronic acquisition boards for the VELO detector. I presented this idea during a central collaboration meeting and was accepted as the coordinator of this project. The results are detailed in Chapter 2 of my habilitation paper, also, they were published in other papers [C9, C10, C26, D5, D6, D8].

In years 2007-2009 commissioning and final tests of various systems of the VELO detector have commenced. The biggest challenge was to confirm the capability of this detector to take physics data and contribute to the trigger of the LHCb experiment. A series of testbeam experiments have been scheduled including high and low voltage stress test, grounding and shielding performance test, space- and time-alignment using pion beam and finally readout chain tests. For the very first time tracks of charged particles and vertices have been reconstructed. All these studies have been done at CERN with proton beam produced by the SPS (Super Proton Synchrotron). Throughout all testbeam experiments I acted as one of the leading experts responsible for software for the emulation and analysis. I also contributed in the sensor alignment studies. The obtained results proved to be of great value for the VELO project and allow for appropriate adjustments and corrections in the final system. The results were summarised and published in the following papers [C13, D7].

The experience gained with operating the emulation and calibration software was also used during the test of novel detection devices for the future high energy experiments. I made a proposal of using modified emulation suite to process and calibrate 3D silicon sensors. The VETRA software project proved to be versatile and flexible. It was used in almost on-line mode to verify the performance of the tested 3D sensors and was used to calibrate the readout DAQ system. This work was documented in two papers [C10, C12].

In 2010 I was selected as one of the critical VELO experts and sent to CERN as LTA (Long Term Attachment) fellow. My primary tasks were related to VELO software preparation and commissioning for the first proton-proton runs.

At the end of 2010 I accepted the position of Assistant Professor with the AGH-UST in Krakow and started to work for the local LHCb group. I became the deputy head of this group responsible for cooperation with foreign institutes from the LHCb Collaboration. Also, I continued my involvement in the VELO software development and maintenance. In 2012 the Krakow group was accepted as a part of the VELO project and I became the leader of the Krakow VELO project.

In order to further enhance the significance of the Krakow group within the LHCb Collaboration I began negotiation with the collaboration's management regarding involvement in the upgrade activities. Together with other sub-detector project leaders we made a proposal for a common front-end silicon strip readout chip that would be designed by the Krakow ASIC group [D11]. Within this project I'm responsible for defining the digital processing chain (zero-suppression and hit detection) and preparing the high level emulation software. Also, I'm involved in modernization of the vertex detector. It's new version – VELOPix - will be operating pixel sensors. The Krakow group is directly involved in design and implementation of the data processing software for the electronic acquisition board Tell40. Our group proposed a novel approach to detector spatial alignment based on massively parallel processing using GPU[6] cards. This strategy is being evaluated by the LHCb Collaboration.

In order to formalize our involvement in the VELO performance studies, and particularly in the radiation damage studies, I put forward a proposal to the RD50 Collaboration Board for the full membership for the Krakow group.

6. Detailed overview of other scientific and research achievements

6.a Publications

Detailed list of publications is given in appendix 5.

Total number of publications: **264**
Publications listed in the Journal Citation Reports (JCR): **250** (before obtaining the PhD **21**)
Habilitation paper „***Performance of the LHCb Vertex Locator and the measurement of the forward-backward asymmetry in*** $B_d \to K^{*0}(892)\mu^+\mu^-$ ***decay channel as a probe of New Physics***", Wydawnictwo JAK, Kraków 2013, ISBN 978-83-934620-9-4

Number of citations: **4126**
Number of citations without the auto-citations: **3651**
Hirsch index (30th Nov 2013, according to Web of Science): **h = 25**
Total Impact Factor: approximately **576,94** (**94,015** for the publication listed in appendix 5)
(Note, for papers published in 2013 I assumed IF from year 2012)

6.b Training and post-doc trips

CERN Geneva	2002r., DELPHI experiment, 6 weeks
Glasgow University	2005 – 2009r., LHCb experiment, post-doc position, 5 years
CERN Geneva	2008r., ACDC1/2 testbeam, LHCb experiment, 2 months
CERN Geneva	2009r., ACDC3 testbeam, LHCb experiment, 2 months

[6] Graphical Processing Unit

CERN Geneva 2010r., LTA fellow with Glasgow University, 11 months

6.c Participation in scientific projects

Polish projects

1) Research subject: „**Studies of the electron-position interactions at LEP collider**"
Role – main participant

Projects related to this research subject

- Special research project: „DELPHI experiment – study of e^+e^- interaction at LEP collider with the DELPHI detector", no. 621/E-78/SPUB/P-03/023/97, SPUB/CERN/P-03/DZ 11/99, SPUB/CERN/P-03/DZ 296/2000-2002

- Grants from the KBN: 2 P03 B 111 16, 2 P03 B 104 19

2) Research subject: „**LHCb experiment at LHC proton collider dedicated for studying CP symmetry violation**"
Main participant

Projects related to this research subject:

- Research project: no. 1P03B 053 28

- Research project: no. 112/E-356/SPB/CERN/P-03/109/2003-2005

- Special research project: no 112/E-356/SPUBM/CERN/P-03/DZ 296/2000-2002

Foreign project (while with Glasgow University)

1) LHCb e-science workpage 2: VELO software, PP/C000277/1, University of Glasgow, application for £0.17M from UK Particle Physics & Astronomy Research Council (PPARC), 2004

2) Experimental Particle Physics Rolling Grant PP/E000290/1 from UK Science and Technology Facilities Council (STFC), University of Glasgow, application for £7.9M, 2006

3) Experimental Particle Physics Rolling Grant ST/H001077/1 from UK Science and Technology Facilities Council (STFC), University of Glasgow, application for £7.0M, 2009

6.d Scientific conferences

Organisation

- ***Workshop on Common ASIC for the LHCb Upgrade***, Kraków 04 - 06/07/2012
  Chair

- *Open Symposium on European Strategy for Particle Physics*, Kraków 10 - 12/09/2012
  Member of the Local Organizing Committee
- *69th LHCb Collaboration Week*, Kraków 09 - 13/09/2012
  Chair

Selected invited talks I gave on the international conferences

- *International Conference on High Energy Physics* **CHEP 2002**
  Amsterdam 24 - 31/06/2002 Netherlands
  "The $\eta_c(2980)$ formation in two-photon collisions at LEP energies"
- *International Conference on the Structure and Interactions of the Photon* **PHOTON 2003**
  Frascati 07 - 11/2003 Italy
  "The Measurement of Hadronic Structure Function of the Electron $F_2^e(z)$"
- *International Europhysics Conference on High Energy Physics* **HEP 2005**
  Lisboa 21 - 27/07/2005 Portugal
  "Photon Structure at LEP"
- *42nd LHCb Collaboration Week*
  Heidelberg 11 - 15/09/2006 Germany
  "VETRA Project in Testbeam"
- *17th International Workshop on Vertex Detectors* **VERTEX 2008**
  Uto Stockholm 27 - 01/08/2008 Sweden
  "Vertex, Track Reconstruction and Luminosity Monitoring at LHCb"
- *Computing in High Energy and Nuclear Physics* **CHEP 2009**
  Praga 21 - 27/03/2009 Czech Republic
  "VETRA - offline analysis and monitoring software platform for the LHCb VELO"
- *Krakow Epiphany Conference* **2010**
  Kraków 05 - 08/01/2010 Poland
  "The LHCb Upgrade"
- *8th International Conference on Radiation Effects on Semiconductor Materials Detectors and Devices* **RESMDD 2010**
  Firenze 12 - 15/10/2010 Italy
  "First results from the LHCb Vertex locator"
- *20th RD50 Workshop on Radiation hard semiconductor devices for very high luminosity colliders* **2012**
  Bari 30/05 – 01/06/2012 Italy
  "Request from Krakow group to join RD50 Collaboration"
- *9th International Conference on Heavy Quarks and Leptons* **2012**
  Praga 11 - 15/06/2012 Czech Republic
  „The LHCb Upgrade"
- *Workshop on Intelligent Tracker* **WIT 2012**
  "FPGA and ASIC based algorithms for the present and upgraded LHCb silicon vertex detector"
  Pisa 03 – 05/05/2012 Italy
- *8th "Trento" Workshop on Advanced Silicon Radiation Detectors (3D and p-type)* **2013**
  "Performance and radiation hardness of the LHCb Velo"
  Trento 18 – 20/02/2013 Italy

As a member of both DELPHI and LHCb Collaborations I gave more than 150 presentations and seminars during the central and working groups meetings.

6.e Membership in international organisations

- Member of the **LHCb Collaboration Board**
- Member of the **RD50 Collaboration Board**
- Member of the **LHCb Upgrade Resource Board (Upgrade Coordinator for Poland)**
- Member of the **VELO Project Executive Board**

6.f Professional evaluation papers

Since 2011 I became involved in Projects "**PL-GRID**" and "**PL-GRID Plus**". Both of them aim at providing computing infrastructure supporting Polish scientific groups. Specifically, I took part in studies regarding new functionality of the High Energy Physics Grid related to massively parallel data processing capabilities. In course of these studies I created two following papers:

1) „Feasibility of using CUDA capable hardware in HEP data analysis"

2) „Concurent and massively parallel data processing for HEP data analysis – conclusions and recomendations"

6.g Honorary positions

- "Honorary Fellowship Position with Glasgow University"
- "Honorary Fellowship Position with Manchester University"

6.h Invited lectures

In 2013 I was invited by the Manchester University to give two lectures. The first one - "Unbinned data analysis techniques in HEP" was related with my analysis project of the rare decay channel $B_d \rightarrow K^{*0}(892)\mu^+\mu^-$, the second was devoted to GPU processing in HEP.

7. Acknowledgement

Firstly, I would like to express my gratitiude for all members of the DELPHI and LHCb experiments for their help and encouragement I received from them. Without their dedication and hard work it would not be possible to successfully operate the DELPHI and LHCb detectors. Special thanks go to my two mentors prof. Bogdan Muryn and prof. Chris Parkes. The first of them introduced me to the fascinating world of high energy physics, also, I'm grateful for discussions and his remarks related with my habilitation project. The second showed me how challenging is to prepare an ambitious scientific plan and how to manage group of people working on a single project.

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