ЯДЕРНА ФІЗИКА

УДК 539.12/539.1.07

© 2011 V. M. Iakovenko[1,2], O. Yu. Okhrimenko[1], V. M. Pugatch[1], S. Barsuk[2], M.-H. Schune[2]

[1] *Institute for Nuclear Research, National Academy of Sciences of Ukraine, Kyiv*
[2] *Laboratoire de l'Accélérateur Linéaire, Université Paris-Sud 11, Orsay, France*

SELECTED PHYSICS MEASUREMENTS FOR THE LHCB EXPERIMENT AND THE RADIATION MONITORING SYSTEM

The LHCb experiment at the Large Hadron Collider (LHC) is dedicated to studies of rare phenomena in b-and c-decays in order to precisely constrain the Standard Model parameters and search for beyond Standard Model signatures. The LHCb detector is fully installed and commissioned; first data from *pp* collisions are being experienced. Physics performance of the LHCb experiment in constraining Standard Model parameters is illustrated with the expected reach on the CKM angle measurements, $B_{d,s}$ mixing phases and the angle γ of unitarity triangle. New physics search in the *b*-sector is discussed at the examples of rare decays $B_s \to \mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$, as well as photon helicity studies in the $B_s^0 \to \varphi\gamma$ mode. Radiation level measurement for the silicon inner tracker operation and beam condition monitoring with the Radiation Monitoring System, developed at Kiev Institute for Nuclear Research, are discussed.

Keywords: LHCb experiment, CP violation, B^0_s-meson radiative decay, radiation monitoring system.

Introduction

The unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix is visualized in terms of six unitarity triangles (UT) of equal area (Jarlskog invariant), quantifying the CP violation. Two out of six triangles have comparable sides, and are of utmost interest for *b*-physics. The knowledge of the UT parameters is compiled [1] in Fig. 1. Owing to the results from B-factories and Tevatron, the precision of UT parameters have significantly improved over the last decade, the UT apex is precisely constrained. The angles are known to the precision of $\Delta\alpha \approx 6^o$, $\Delta\beta \approx 1^o$ and $\Delta\gamma \approx 20^o$, where β and γ are still dominated by experimental error. At the same time, the precision of sides is dominated by theoretical uncertainties. The R_b side determination suffers from theoretical uncertainty of ~ 8 % on the V_{ub} measurement, while the R_t side (V_{td}/V_{ts}) is known to a precision of ~ 5 %. For both R_b and R_t limitations come from lattice calculations, while R_t improvement is expected from radiative penguin decay studies. Comparing precision of the UT angle determination to the precision of the opposite side, we notice, that constraining the apex with the (β, R_b) is limited by the R_b precision, while constraining the apex with (γ, R_t) is limited by the precision on γ. Already present knowledge of the R_t requires the angle γ to be measured with a precision of 5^o. A determination of the UT elements, discussed above, is mediated by b-physics ($B_{d,s}$ mixing rates and phases, penguin transitions, CP asymmetry in b-decays) and also c-physics (V_{cs} normalization) studies.

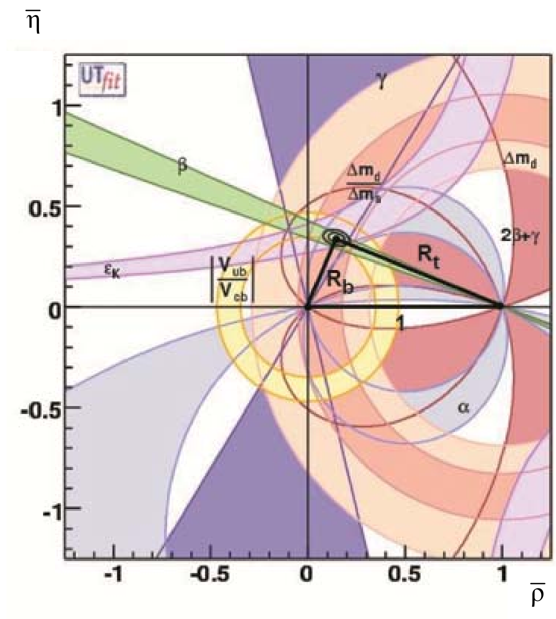

Fig. 1. Unitarity triangle fit by the UTfit group.

The LHCb Detector

LHCb (Large Hadron Collider beauty) is a dedicated experiment to study CP violation and other rare phenomena in *b*-decays [2]. The LHCb detector is a single-arm forward spectrometer (Fig. 2), covering 10 - 300 (15 - 250) mrad acceptance for *x*(*y*) projections and insuring efficient track and neutral particle reconstruction, robust trigger and particle identification. The experiment will run at a reduced LHC luminosity tuneable in the range $2 \div 5 \cdot 10^{32}$ cm^{-2} s^{-1}. At LHCb a 10^{12} $b\bar{b}$ pairs will be annually produced, with about 43 % of the $b\bar{b}$

pairs entering detector acceptance. All the b species will be produced, with the biggest samples of B_u, B_d, B_s and Λ_b, $B_u : B_d : B_s : B_c : \Lambda_b \approx$ 4:4:1:0.1:1. Complementing detailed studies of lighest B mesons at B-factories and Tevatron, the LHCb experiment is expected to significantly contribute to the studies of B_s, in particular time resolved studies, B_c and Λ_b.

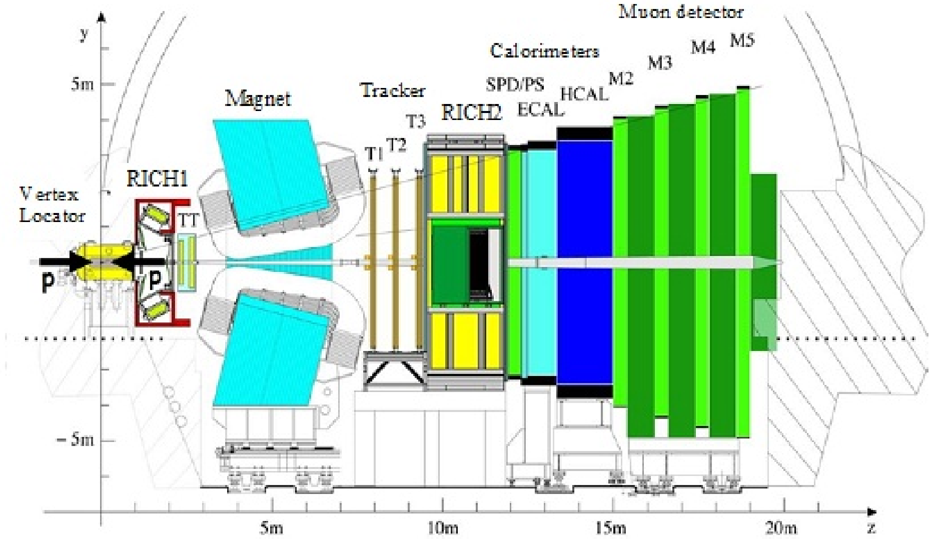

Fig. 2. Side view of the LHCb detector from inside of the LHC machine loop.

The b-physics studies at LHCb benefit from good track reconstruction, precise recontruction of well displaced (on average 7 mm) b-decay vertex, powerful particle identification, large rapidity coverage, and anticipated very high statistical yields. However, the analysis has to cope with high event multiplicities, and forward detector geometry which prevents full event reconstruction.

During 2010 and 2011, the first years of LHC operation, the machine is running at the reduced energy of $E_{CM} = 7$ TeV, which then will be substantially increased. The luminosity in 2010 is foreseen to be significantly lower, and a data sample of around 100 - 200 pb^{-1} was expected to be accumulated in 2010, whereas 1 fb^{-1} is projected for 2011. Thereafter progressive reach of nominal operation conditions with $E_{CM} = 14$ TeV and annual integrated luminosity of 2 fb^{-1} is planned.

In LHCb passing from the pp interaction region, particles meet a vertex locator (VELO), a warm dipole magnet with integrated field 4 Tm (from z = 0 to z = 10 m, see Fig. 2), a tracking system, two ring imaging Cherenkov detectors (RICH), a system of calorimeters and a muon detector. A more detailed discussion of the LHCb detector can be found elsewhere [3].

Radiation dose, fluxes and background monitoring at LHCb

The radiation loads during 10 LHC-years of normal operation will ought 50 MRad at closest to Interaction Point regions [4]. Especially, high radiation loads are dangerous for Si-detectors and their readout electronics, which switches on only in case of stable beam. To control radiation doses and beam condition the following tools are used: *Beam Condition Monitor* (*BCM*) [5]; *Beam Loss Scintillator (BLS)* [6]; *LHC Beam Loss Monitors* (*BLM*) [7]; *Beam Phase and Intensity Monitor* (*BPIM*) [8]; *Radiation Monitoring System* (*RMS*). The RMS is presented in detail below.

The Radiation Monitoring System for the LHCb Inner Tracker

The level of charged hadron fluxes [4] at the location of the silicon sensors of the IT-2 station varies from about $10^4\,\text{cm}^{-2}\text{s}^{-1}$ to $10^5\text{cm}^{-2}\text{s}^{-1}$ at the nominal LHCb luminosity. The main goal of the Radiation Monitoring System (RMS) is a measurement of the radiation dose load onto silicon micro-strip sensors of the LHCb Inner Tracker (IT) as well as front-end electronics in order to exclude their damage as a result of an unexpected radiation incident, i.e. change of the beam trajectory, partial beam loss in the region of the detector etc.

The RMS is based on the Metal Foil Detector (MFD) technology [9 - 11]. The principle of the MFD operation is Secondary Electron Emission (SEE) from the metal foil surface (emission layer ~ 10 - 50 nm) caused by impinging charge particles. SEE causes positive charge on a foil which is readout by sensitive Charge Integrator (ChI). Several MFD advantages have determined our choice for the IT RMS: the possibility to provide extremely low mass of the detecting material (from practical point of view – few tens μm); simple readout electronics (charge integrators and scalers); low operating voltage (24 V); high radiation tolerance; long term performance with minimal maintenance and low cost.

The MFD is a 5-layer structure manufactured out of 50 μm-thick Al foils supported by insulating epoxy frames. The central sensitive layer is connected to the readout electronics, while two neighbouring (from both sides) accelerating layers are biased by positive voltage (HV, +24 V) to reduce recombinations after SEE. The two outer shielding layers are grounded. RMS Sensor and accelerating layers are divided into 7 parts (110 × 75 mm, with a layout which is similar to IT silicon sensors size). The RMS consists of 4 modules (Top, Cryo, Bottom, Access) containing 7 sensors each (in total 28 sensors), which are located at IT-2 station (~ 8.4 m from interaction point) around the beam-pipe (Fig. 3). The RMS readout electronics consists out of the six 5-channel sensitive ChIs [9, 10] and 32-channels LVDS VME-scaler (C.A.E.N. V830LC). The ChIs were developed at INR (Kyiv, Ukraine) and have been modified at MPIfK (Heidelberg, Germany). The ChI's principle of operation includes a current-to-frequency converter allowing achieving high dynamic range (up to10^6). A current from the stable external source (250 pA) is injected to the ChI's inputs to make base lines (~ 22 kHz). Some RMS features are presented in the Table.

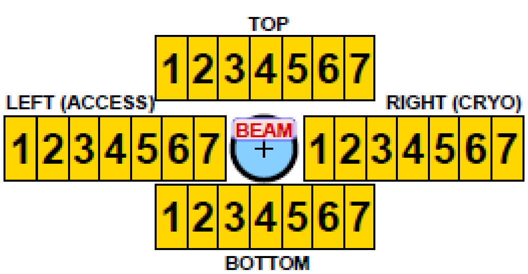

Fig. 3. Schematic view of the RMS-modules location at IT-2 station with sensor's numbering (view from the interaction point).

Typical features of the RMS

Name	Value
ChI conversion factor	10 fA - 1 Hz
SEE factor	~ 25 SE/MIP
RMS response	30 MIP/cm^{2}s - 1 Hz

MFD sensors, patch-panels and ChIs are connected by 28 screened twisted pair cables ~ 5 and ~ 25 m long, respectively. Patch-panels located at IT-2 station near the Service Boxes and contains RC-filters (R = 1 MΩ, C = 1 μF) to stabilize the High Voltage.

The Charge Integrators are located at the Bunker and connected with VME-scaler via 60 m long multiconductor screened twisted pair cables. VME-scaler via VME-to-USB bridge connected with PC where RMS readout software based on supervisory control and data acquisition system is installed [10].

The data from the RMS are displayed at the Control Room on-line and stored for the off-line analysis to calculate the radiation load on the Si-sensors of the IT and also the RMS data can be used to measure relative luminosity and to control the Interaction Point position.

The RMS is designed for the monitoring of charge particle fluxes exceeding ~ 300 MIP/cm2s. During the first collisions at the LHC in November'09 - March'10 proton beams intensities were not high enough to produce charge particle fluxes that could be detected by the RMS. Yet, there were three incidents when charge particle fluxes have evoked the RMS response. It have happened during aperture scan (midnight 02-03/12/2009), high-intensity beam collisions (14/12/2009) and magnet kicker injection time scan (07/03/10) with the beams energy of $\sqrt{s}$ = 900 GeV. As example, the RMS response on beam interaction during aperture scan is shown in Fig. 4. The maximum charged particle fluxes were estimated, during the November-December operation, as well as their distribution over the RMS-sensors were compared with the Monte-Carlo simulation. Fluxes as high as ~ 1.7 · 10^4 and ~ 10^3 cm^{-2}s^{-1} were detected in case of vertical-scan and high-intensity beams collisions, respectively. Monte Carlo simulation was done for 450 GeV protons to estimate the charged particle fluxes in the RMS region. Simulated fluxes were compared to the measured fluxes during the aperture scan (Fig. 5). One can notice a good agreement between those two. The RMS has demonstrated expected performance with respect to the ability to detect spikes of the radiation background as well as long term reliable operation.

Standard Model parameter measurements

The examples of precision studies of Standard Model parameters, expected from LHCb, the $B_{d,s}$ mixing phases and the Unitarity Triangle γ angle measurements are discussed below.

$B_{d,s}$ mixing phases

The exploration of the UT angles covers the mixing phases, $\varphi_d = 2\beta$ for B_d system and $\varphi_s = -2\chi$ for B_s system, and the α and γ UT

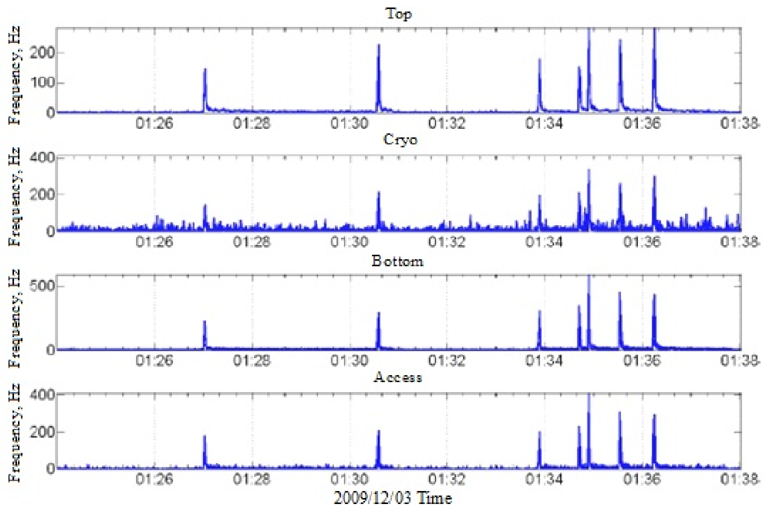

Fig. 4. The RMS response on beam interaction during aperture scan (03/12/09).

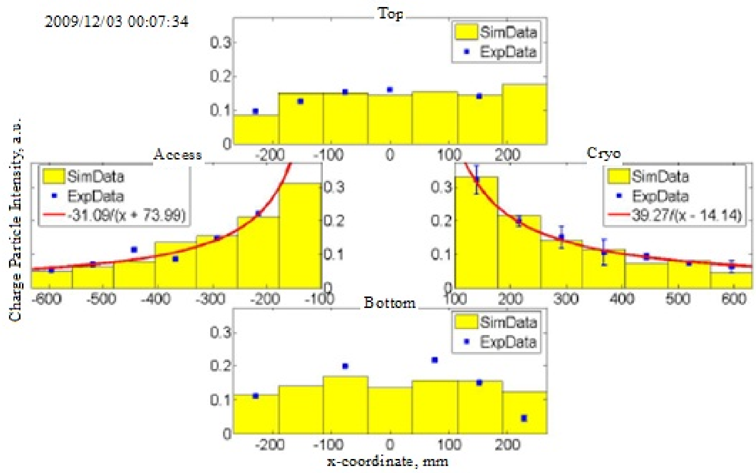

Fig. 5. Comparison between the RMS real and MC simulated data.

angles. Most awaited are the study of φ_s phase, which in the SM is expected to be small, 0.0037, and thus attractive for the New Physics (NP) search, and the angle γ to constrain the UT triangle in combination with the R_t side and to search for possible NP contribution to loops by comparing the tree-mediated processes to those involving penguin loops. These studies rely on the CP (often time-dependent) asymmetry measurements.

The first asymmetry study will be that of the φ_d phase, using the $B_d \to J/\psi K_s$ decay. Comparing to the value well-established by B-factories, provides a powerful systematics control for further asymmetry studies. Also important is to establish the direct CP violating term from the $B_d \to J/\psi K_s$ decay asymmetry. In one year (2 fb^{-1} integrated luminosity), having a $240\,k$ clean (S/B ~ 1.4) signal events reconstructed, LHCb should be able to achieve the precision of 0.02 on the $\sin 2\beta$ value. This can be compared to the BaBar+BELLE combined precision of ~ 0.018 expected at the end of the B-factories, and to an error of 0.01 for $30\ \text{fb}^{-1}$ expected with ATLAS and CMS [12].

The best channel for the φ_s phase measurement is $B_s \to J/\psi\varphi$, where $J/\psi \to \mu^+\mu^-$ and $\varphi \to K^+K^-$ follow. $B_s \to J/\psi\varphi$ is a $P \to VV$ decay, and the final state is thus a mixture of $\text{CP} = +1$ and CP=-1 components. To disentangle CP eigenstates, a partial wave analysis is required. LHCb is expected to reconstruct $131\,k$ $B_s \to J/\psi\varphi$ events with S/B ratio of 10. This results in a φ_s sensitivity of 0.01 for the full b physics integrated luminosity of $10\ \text{fb}^{-1}$.

A by-product of this analysis is the $\Delta\Gamma_s$ measurement. The expected LHCb sensitivity on $\Delta\Gamma_s/\Gamma_s$ of 0.01 is small compared to the SM prediction of $\Delta\Gamma_s/\Gamma_s \sim 0.1$.

Following the $\delta\beta^{NP}$ estimation, LHCb will compare the χ angle from tree-mediated diagram, $B_s \to J/\psi\varphi$, to that from pure penguin decay, $B_s \to \varphi\varphi$. This will yield an estimate of the NP contribution, $\delta\chi^{NP} = \chi^{tree} - \chi^{penguin}$, with sensitivity of 3° in one year.

The NP contribution in B_s mixing could be parametrized via $M_{12} = (1 + h_s e^{2i\sigma s})\cdot M_{12}^{SM}$, where M_{12}^{SM} is the dispersive part in the SM. Then Δm_s and φ_s measurements can be used to constrain NP in the oscillation [13]: $\Delta m_s = \Delta m_s^{SM}|1 + h_s e^{2i\sigma s}|$, $\varphi_s = \varphi_s^{SM} + arg(1 + h_s e^{2i\sigma s})$. For $2\sigma_s \neq n\pi$, LHCb is expected to constrain $h_s < 0.1$ at 90 % confidence level (CL) in one year.

CKM angle γ

Precise γ measurements will allow to constrain the apex of the UT and also to search for possible NP effects in loops by comparing γ value as determined from the tree-mediated diagrams to that from the processes involving loops.

The CP violation in purely tree process, $B_s \to D_s^+K^-$ ($B_s \to D_s^-K^+$), where both diagrams are proportional to λ^3, followed by $D_s \to KK\pi$, occurs due to the interference via mixing. The corresponding phases are $\Delta \mp (\gamma + \varphi_s)$, where Δ is the strong phase difference. Experimentally, four tagged time-dependent rates are fitted, and the phases Δ and $\gamma + \varphi_s$ are measured simultaneously. The K/π separation is essential for the analysis to decrease contribution from the $B_s \to D_s\pi$ decay, which has a 20 times larger branching fraction. Applying the LHCb particle identification, a residual contamination of $B_s \to D_s\pi$ is shown on top of the $B_s \to D_sK$ invariant mass spectrum in Fig. 6. The expected LHCb annual yield [14] is $6.2\,k$ events with S/B > 1.4 at 90 % CL. The error on $\gamma + \varphi_s$, 10° in one LHCb year, directly translates to the sensitivity of γ, assuming that a small value of φ_s is measured with the $B_s \to J/\psi\varphi$ decay.

A class of $B \to D^{(*)}K^{(*)}$ decays provides a powerful tool for γ measurement. Various methods [15 - 17] are summarized in [12]. Applying them or their combinations to variety of $B \to DK$ decays [18], LHCb is expected to achieve a statistical error of ~ 4° in one year.

$B_d \to \pi\pi$ and $B_s \to KK$ channels allow γ determination sensitive to possible NP contribution to the penguin loop. Four time-dependent asymmetries are measured with γ, φ_d, φ_s, and relative penguin-to-tree contribution $P/T = de^{i\theta}$ as parameters. The phases φ_d and φ_s are measured separately. Using the U-spin symmetry assumption [19], $d_{\pi\pi} = d_{KK}$ and $\theta_{\pi\pi} = \theta_{KK}$, which allows not only to solve system for γ, but since the system becomes overconstrained, also to check the initial assumption of U-spin symmetry. In one year LHCb is expected to reconstruct $25\,k$ $B_d \to \pi\pi$ events and $37\,k$ $B_s \to KK$ events with S/B of 2 and > 7 correspondingly, leading to σ(γ) ~ 4° under the assumption of perfect U-spin symmetry.

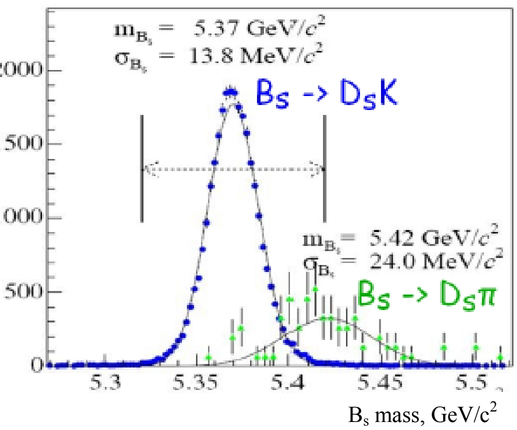

Fig. 6. Invariant mass of D_sK from $B_s \to D_sK$ decay with $B_s \to D_s\pi$ contribution.

Search for New Physics

The LHCb experiment will search for NP in CP violation and rare decays in the heavy quarks sector. An overview of its physics program in the rare decays of B hadrons is given, illustrated by few key examples: measurements of the $B_s \to \mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$ decay modes, study of the photon helicity using the $B_s \to \varphi\gamma$ mode.

Search for $B_s \to \mu^+\mu^-$

The helicity suppressed $B_s \to \mu^+\mu^-$ decay is due to very rare loop diagram in the Standard Model (SM) and its Branching Ratio (BR) is expected to be extremely small: (3.35 ± 0.32) · 10^{-9} [20] but NP models such as for example supersymmetry could enhance it up to 100 times. The best current limit is achieved by CDF: BR <4.7 · 10^{-8} at 90 % CL [21].

The LHCb experiment is well suited for studying this decay due to high trigger efficiency, good muon identification and an excellent invariant mass resolution. The analysis [22] is based on three variables: the $\mu^+\mu^-$ invariant mass, and two likelihood variables, one describing the particle identification information and the second one the geometrical information of the decay (impact parameter significance of the muons, B_s proper time, impact parameter of the B_s, distance of closest approach between the two muons, muon isolation). Likelihood function of these three variables will be calibrated on real data using control channels. The three dimensions space defined by these variables is divided in bins. The estimated background and the expected signal events for a given BR in each of these bins are used to compute the exclusion and discovery potential of the LHCb experiment [23].

Study of the $B \to K^* \mu^+ \mu^-$ decay mode

Decays generated by the flavour-changing neutral current, such as $B \to K^* \mu^+ \mu^-$ are also very interesting to probe NP. The diagrams contributing to this decay mode are shown in Fig. 7.

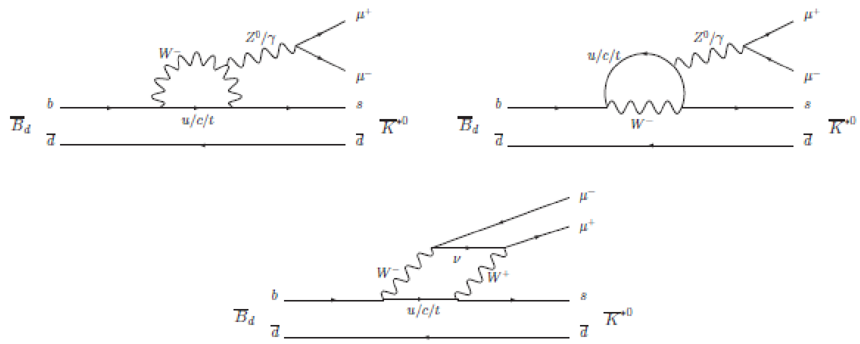

Fig. 7. The Standard Model Feynman diagrams for the decay $B \to K^* \mu^+ \mu^-$.

Among the observables which can be built, the forward-backward asymmetry A_{FB} in the $\mu^+\mu^-$ rest frame as a function of the $\mu^+\mu^-$ invariant mass is of interest, and in particular the invariant mass value, s_0, where A_{FB} crosses zero. The value s_0 can be precisely predicted by the SM and NP could give a sizeable deviation to this prediction. Some first measurements have been conducted at B factories, but are statistically limited. LHCb is expected to collect 7200 events for 2 fb^{-1} with a background over signal ratio around 0.2; to be compared with the 450 events expected from the Belle and BABAR experiments together. By fitting a linear function to A_{FB} around the crossing region, a precision on s_0 of 0.46 GeV^2 with 2 fb^{-1} of data is forseen [24]. In addition, with large statistics, using the whole set of angular observables ($\cos\Theta_\ell$, $\cos\Theta_K$ and φ), LHCb can measure [22] the transversity amplitudes as a function of the dimuon mass [25]. The two crucial points for the study of the angular distributions of the decay products of the $B \to K^* \mu^+ \mu^-$ decay mode are the understanding of the event acceptance as a function of the whole set of variables ($\cos\Theta_\ell$, $\cos\Theta_K$ and φ) and of the $\cos\Theta_\ell$, $\cos\Theta_K$ and φ distributions for the background.

Study of the photon helicity

The SM predicts a right-handed component in the photons generated by the $b \to s\gamma$ transitions to a level of $O(m_s / m_b)$. In several extensions of the SM, the photon can acquire an appreciable right-handed component due to chirality flip in the transition [26] with a small impact on the SM value of the branching ratio. One of the experimental techniques to probe the photon helicity is via mixing-induced CP asymmetries [27]. The combination of the BELLE and BABAR measurements of the time dependent CP asymmetry using the $B \to (K_s^0 \pi^0)\gamma$ decay mode [28] leads to an uncertainty of ~ 0.16 on the fraction of wrongly polarized photon. A similar study can be done using the $B_s \to \varphi\gamma$ decay mode. A signal sample of 11000 events for 2 fb^{-1} with a background over signal ratio smaller than 0.9 at 90 % CL is expected [22]. This should allow to measure $\sin 2\Psi$ with a 20 % statistical uncertainty. The crucial point of this analysis is to understand the proper time acceptance.

$B_s \to \varphi\gamma$ Reconstruction

In LHCb physics will be studied in high energy region. New energies apparently will lead to the discovery of new processes and new particles - New Physics. The study of radiative penguin decays provides an efficient tool to search for physics beyond the Standard Model (SM). Evidences of NP may occur via transitions induced by flavor changing neutral currents in the loops of penguin diagrams. In addition radiative decays provide independent determination of the $|V_{td}/V_{ts}|$ ratio of the CKM matrix elements ratio from simultaneous measurement of $B^0 \to K^*(892)^0\gamma$ and $B_s^0 \to \varphi\gamma$. In the framework of the SM, radiative decay $B_s^0 \to \varphi\gamma$ is described by the $\bar{b} \to \bar{s}\gamma$ electromagnetic penguin diagram (Fig. 8).

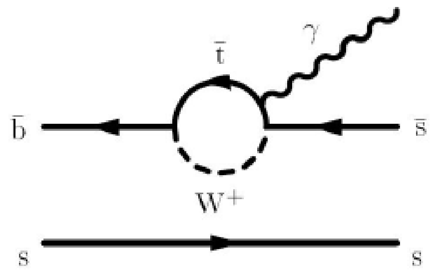

Fig. 8. Diagram describing the dominant process for the $B_s^0 \to \varphi(\to K^+K^-)\gamma$.

This measurements are very delicate and have to be very precise, to do this reasonable selection algorithm is essential.

Monte Carlo simulation

A MC simulation is used to determine the reconstruction efficiency, understand the nature of the background, optimize criteria of the B_s-candidate selection and obtain the annual yield and B/S ratio for the $B_s^0 \to \varphi(\to K^+K^-)\gamma$ decay reconstruction. The simulation includes our best knowledge of physics of the processes under investigation, the LHCb detector, the LHCb trigger and the event reconstruction. Studies presented here, are performed within standard LHCb software.

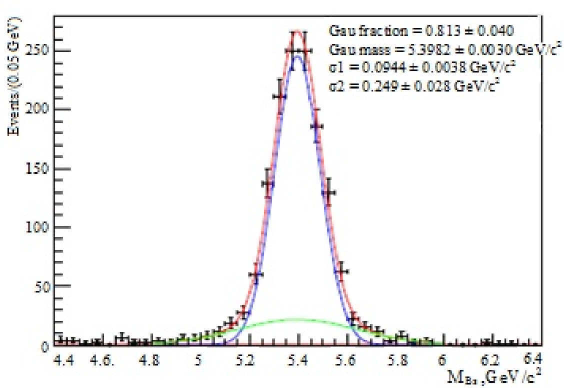

Fig. 9. $\varphi\gamma$ candidates distribution obtained from MC DC06 and matched to truth. The mass pick was fit with two gaussians in $\pm 3\sigma$ region. The effective mass resolution is found to be about 120 MeV/c.

The procedure of reconstruction is performed in several steps. Two charged tracks of opposite charge should be identified as kaons. The two kaons are combined to form the φ-meson. The invariant mass of the K^+K^- pair has to be compatible with the φ mass. Finally the φ-candidate is combined with an energetic photon to form a B_s-candidate.

Cut description, selection procedure and optimization are described in details in [29].

In Fig. 9 the B_s invariant mass is presented with all set of selection cuts applied. This distribution is fitted with two Gaussians. The resolution is found to be: $\sigma(M_{B_s}) = 120 \pm 3$ MeV/c^2.

We have reconstructed and selected 1285 signal events matched to truth within 2 standard deviation around the B_s mass. Out of these 1285 events 867 passed the L0 trigger yielding the L0 efficiency of $\varepsilon_{L0} = 0.67$.

Efficiency, Annual yield and B/S ratio

Total efficiency includes trigger efficiency: triggered (ε_{trig}), reconstructed and selected (ε) $B_s^0 \to \varphi\gamma$ events: $\varepsilon_{tot} = \varepsilon \cdot \varepsilon_{trig}$. The selection and reconstruction efficiency is calculated as the number of signal events selected and reconstructed (1285), divided by the number generated with Monte Carlo method (131k), $\varepsilon = 1285/131000 = 0.01$. After all selection cuts were applied on $b\bar{b}$-inclusive sample – four background events fall in the wide B_s mass window. Three of these events have real φ, but combinatorial photon. In the forth event a π^+ was erroneously identified as K^+ to form a φ-candidate. Two specific backgrounds considered are $B^0 \to K^*(890)^0\gamma$ and $B_s^0 \to \varphi\pi^0$. The signal sample of $210\,k$ events was used to determine $K^*\gamma$ contribution with the set of the selection cuts applied. Kinematically, $B_s^0 \to \varphi\gamma$ and $B \to K^*\gamma$ decays are much alike and no large difference in kinematical and vertex parameters is observed. After all selection cuts were applied we are left with no events in the B_s wide mass window.

Assuming that $Br(B^0 \to K^*(890)\gamma) = (4.01 \pm 0.2) \cdot 10^{-5}$ [30], the B/S ratio due to $B_{B\to K^*\gamma}$ is estimated to be $B_{B\to K^*\gamma}/S < 0.004$ at 90 % CL.

The contribution from $B_s^0 \to \varphi\pi^0$ decay was estimated assuming the same acceptance, selection and trigger efficiency as for $B_s^0 \to \varphi\gamma$, and $Br(B_s^0 \to \varphi\pi^0) < 3.5 \cdot 10^{-6}$, $B_{B\to\varphi\pi^0}/S < 0.06$ at 90 % CL.

The annual signal yield for $B_s^0 \to \varphi\gamma$ before the trigger can be calculated as

$$S_{annual} = N_{bb} \cdot 2 \cdot f_s \cdot Br(B_s^0 \to \varphi\gamma) \cdot Br(\varphi \to K^+K^-) \cdot \varepsilon \cdot A, \quad (4)$$

where $N_{b\bar{b}}$ is the number of $b\bar{b}$ quark pairs per year (10^{12}), factor 2 represents the fact that the pair $b\bar{b}$ forms, the probability for a $\bar{b}$-quark to hadronize into a B_s is f_s = 10 % [2], $Br(B_s^0 \to \varphi\gamma) = (5.7^{-1.9}_{+2.2}) \cdot 10^{-5}$ [30] and $Br(\varphi \to K^+K^-) = 49.2 \pm 0.6\,\%$ [30], $A = 0.28$ is the geometrical acceptance for the $(B_s^0 \to \varphi\gamma)$ and the selection and reconstruction efficiencies defined above, the signal annual yield is then $S_{annual} = 15.4\,k$ selected events before the trigger. To obtain the B/S ratio one has to calculate annual background yield before the trigger:

$$B_{annual} = N_{bb} \cdot \varepsilon \cdot A, \qquad (5)$$

where $N_{b\bar{b}}$ the number of $b\bar{b}$ quark pairs per year, $A = 0.44$ is the geometrical acceptance for pair of $b\bar{b}$ quarks and ε is the selection and reconstruction efficiencies for $b\bar{b}$ quark pair.

Rescaling the background estimates to the tight B_s mass window (±200 MeV/c^2) the value $B/S < 1.9$ at 90 % CL was obtained. After L0 trigger was applied the value we obtained for the annual yield is: $S_{L0} = 10.3\,k$ events.

Example of expected mass plot for 200 pb^{-1}

The estimations made on amount of data taken in 2010 for the scenario when LHC will have 720 bunches circulating with $7 \cdot 10^{10}$ intensity at β = 2.5 m are ~ 100 pb^{-1} per month [31]. We made an estimation on the mass plot we could obtain with 200 pb^{-1}, which corresponds to estimated amount of data taken.

The background shape obtained by relaxing selection cuts was fitted with second polynomial. The ratio between narrow mass region ($\pm 2\sigma$) to the wide mass region (± 1 GeV/c^2) is found to be 0.25.

The number background was estimated for four events, thus corresponding to a background yield of roughly 3600 events in the wide mass region for 200 pb^{-1}. Assuming the ratio B/S = 0.88 and between mass windows, we obtain the amount of signal to be generated in narrow mass window, 1030 events after L0 trigger for 200 pb^{-1}. The total mass function that describes the distribution of signal and background together was using fit parameters from double Gaussian in Fig. 9 for signal and second order polynomial for background. The obtained mass plot is presented in Fig. 10. After the signal and background were generated, once again they were fitted with double Gaussian and second order polynomial to assure the accuracy of the fit.

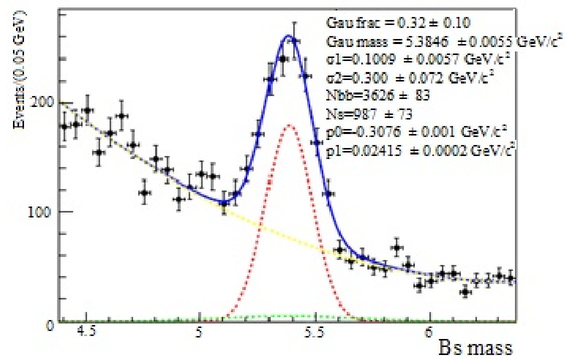

Fig. 10. Example of the B_s mass plot for 200 pb^{-1} data.

As can be seen from the Fig. 10 the number of signal and background are consistent with what was the inputs of the generation, as well as the parameters of the polynomial.

Conclusions

In summary, the LHCb experiment will enter the precision physics studies soon after the startup of LHC. By the end of 2010, with about 100 pb^{-1} integrated luminosity, a large number of signal events should be available for many channels. Thereafter, with a nominal integrated luminosity of 2 fb^{-1} per year, LHCb will systematically deliver unprecedented precision to many Standard Model parameter measurements, as well as the New Physics effect searches via rare decays.

REFERENCES

1. *Bona M., Ciuchini M., Franco E. et al.* [UTfit Collaboration] // www.utfit.org
2. *LHCb Collaboration***.** LHCb Reoptimized Detector Design and Performance: Technical Design Report LHCb // CERN-LHCC-2003-030. - 137 p.
3. *LHCb collaboration*. The LHCb Detector at the LHC / A.A. Alves, L.M. Andarade Filho, A.F. Barbosa, ..., V.M. Iakovenko et al. // JINST. - 2008. - No. 3. - P. 42 - 43.
4. *Talanov V*. Radiation Environment at the LHCb Inner Tracker Area // CERN-LHCb-Note-2000-013. - 21 p.
5. *Mangus H*. Summary of Simulations for the Beam Conditions Monitor at the LHCb: Thesis // LHCb-2008-027 (CERN). - Geneve, 2008. - 84 p.
6. *Guaglio G*. Reliability of the Beam Loss Monitors System for the Large Hadron Collider at CERN: Thesis // CERN-THESIS-2006-012. - Geneve, 2006. - 246 p.
7. *Guaglio G., Dehning B., Santoni C.* Reliability Considerations on the LHC Beam Loss Monitors System // AIP Conference Proceedings. - Vol. 773, Issue 1. - DOI: 10.1063/1.1949526. - Universite

Blaise Pascal, 2005. - P. 191 - 1964.
8. *Guzik Z., Jacobsson R.* Beam Phase and Intensity Monitor (BPIM) for the LHCb Experiment // CERN-LHCb-2006-055; Proc. 12th Workshop on Electronics for LHC and Future Experiments (Valencia, Spain, 25 - 29 Sep. 2006). - Valencia, 2006. - P. 121 - 125.
9. *Radiation* Monitoring System for the LHCb Inner Tracker / M. Agari, …, V. Iakovenko, O. Okhrimenko, V. Pugatch et al. // CERN-LHCb-2007-062. - 15 p.
10. *Пугач В.М., Охріменко О.Ю., Яковенко В.М. та ін.* Система радіаційного моніторингу внутрішнього трекера експерименту LHCb // Український фізичний журнал. - 2009. - Т. 54, № 4. - С. 419 - 427.
11. *Pugatch V.M., Aushev V.E., Bauer C. et al.* Metal Foil Detectors and their applications // Nucl. Instr. Meth. - 2004. - Vol. A535. - P. 566 - 569.
12. *Schune M.-H.* Investigating the physics case of running a B-factory at the (5S) resonance: Talk given at the 5th SuperB workshop Paris, May 9 - 11, 2007.
13. *Ligeti Z., Papucci M., Perez G.* Implifications of the measurements of the $B_s^0 - \overline{B}_s^0$ mass difference // Phys. Rev. Lett. - 2006. - Vol. 97, No. 10. - P. 101801.
14. *Cohen S., Merk M., Rodrigues E.* $\gamma + \varphi_s$ sensitivity studies from combined $B^0_s \to D_s\pi^+$ and $B^0_s \to D^\pm_s K^{-+}$ samples at LHCb // CERN-LHCb-Note-2007-041. - 30 p.
15. *Gronau M., London D.* On determing a weak phase from charged B-decay assymetries // Phys. Lett. - 1991. - Vol. B265. - P. 172 - 176.
16. *Atwood D., Dunietz I., Soni A.* Enhanced CP Violation with $B \to KD^0$ Modes and Extraction of the CKM Angle gamma // Phys. Rev. Lett. - 1997. - Vol. 78, No. 17. - P. 3257 - 3260.
17. *Giri A., Grossman Yu., Soffer A., Zupan J.* Determining γ using $B^\pm \to DK^\pm$ with multibody D decays // Phys. Rev. D. - 2003. - Vol. 68, No. 5. - P. 054018.
18. *Patel M.* Including $B^\pm \to D^* K^\pm$ Decays in the Determination of γ via Atwood-Dunietz-Soni Method at LHCb // LHCb-2007-043. - 22 p.
19. *Fleischer R.* New Strategies to Extract β and γ from $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$ // Phys. Lett. - 1999. - Vol. B 459. - P. 306.
20. *Blanke M., Buras A.J., Guadagnoli D., Tarantino C.* Minimal Flavour Violation Waiting for Precise Measurements of ΔM_s, $S_{\psi\phi}$, A^{S}_{SL}, $|V_{ub}|$, γ and $B^0_{s,d} \to \mu^+\mu^-$ // TUM-HEP-626/06; JHEP 0610 (2006) 003; arXiv:hep-ph/0604057v5.
21. *CDF Collaboration*. Search for $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ Decays with 2 fb^{-1} of *pp* Collisions // Phys. Rev. Lett. - 2008. - Vol. 100, Issue 10. - P. 101802.
22. *LHCb Collaboration.* Roadmap for selected key measurements of LHCb / B. Adeva, M. Adinolfi, A. Affolder, …, V.M. Iakovenko et al. // LHCb-PUB-2009-029; arXiv:0912.4179v2. - Geneve: CERN, 2009. - 372 p.
23. *Read A.L.* Modified frequentist analysis of search results (the CL_s method) // CERN Yellow Report 2000-005. - 21 p.
24. *Egede U.* Angular correlations in the $B \to K^* \mu^+\mu^-$ decay // LHCb-2007-057 (CERN) - 13 p.
25. *Kruger F., Matias J.* Probing new physics via the transverse amplitudes of $B \to K^* \ell^+ \ell^-$ at large recoil // Phys. Rev. D. - 2005. - Vol. 71, Issue 9. - P. 094009; arXiv:hep-ph/0502060.
26. *Mohapatra R.N., Pati J.C.* Left-right gauge symmetry and an "isoconjugate" model of CP violation // Phys. Rev. D. - 1975. - Vol. 11, Issue 3. - P. 566 - 571; *Senjanovic G., Mohapatra R. N.* Exact left-right symmetry and spontaneous violation of parity // Phys. Rev. D. - 1975. - Vol. 12, Issue 5. - P. 1502 - 1505; *Senjanovic G.* Spontaneous breakdown of parity in a class of gauge theories // Nucl. Phys. B. - 1979. - Vol. 153. - P. 334 - 364; *Haber H.E., Kane G.L.* The search for supersymmetry. Probing physics beyond the standard model // Phys. Rep. - 1985. - Vol. 117. - P. 75.
27. *Atwood D., Gronay M., Soni A.* Mixing-induced CP Asymmetries in Radiative B Decays in and beyond the Standard Model // Phys. Rev. Lett. - 1997. - Vol. 79. - P. 185 - 188 [arXiv:hep-ph/9704272].
28. *HFAG Collaboration*: http://www.slac.stanford.edu/xorg/hfag/
29. *Iakovenko V.M.* Selection with the DC06 Monte Carlo of the radiative penguin decay $B_s \to \varphi\gamma$ at LHCb // CERN-LHCb-INT-2010-014. - 19 p.
30. *Amsler C., Doser M., Antonelli M. et al.* Review of particle physics (Particle Data Group) // Phys. Lett. - 2008. - Vol. B 667. - P. 1 - 1340.
31. *LHC Programme Coordination web page*: http://lpc.web.cern.ch/plc/.

В. М. Яковенко, О. Ю. Охріменко, В. М. Пугач, С. Барсук, М.-Е. Шуне

ДЕЯКІ ФІЗИЧНІ ВИМІРЮВАННЯ В ЕКСПЕРИМЕНТІ LHCB ТА СИСТЕМА РАДІАЦІЙНОГО МОНІТОРИНГУ

Головною метою експерименту LHCb, розміщеного на Великому адронному колайдері (LHC) є вивчення рідкісних явищ в розпадах b- та c-кварків для точної перевірки параметрів стандартної моделі (СМ) елементарних частинок, а також пошук явищ за рамками СМ. Детектор LHCb повністю встановлено та введено в експлуатацію – отримано перші дані протон-протонних зіткнень при енергії $E_{\text{с.ц.м.}}$ = 900 ГеВ та $E_{\text{с.ц.м.}}$ = 7 ТеВ. Характеристики експерименту LHCb дають змогу досягати очікувану точність вимірювання кутів матриці Кабібо - Кобаяші - Маскави, фаз змішування $B_{d,s}$-мезонів та кута γ трикутника унітарності. Обговорено пошук сигналів нової фізики в b-секторі на прикладі рідкісного розпаду $B_s \to \mu^+\mu^-$, а також вивчення спіральності фотона в розпаді $B_s^0 \to \varphi\gamma$. Обговорено вимірювання рівня радіаційних навантажень та їхній вплив на роботу кремнієвої трекової системи та контроль стану пучка за допомогою системи радіаційного моніторингу, розробленої в ІЯД НАН України.

Ключові слова: експеримент LHCb, порушення CP-парності, радіаційний розпад B^0_s-мезона, система радіаційного моніторингу.

В. Н. Яковенко, А. Ю. Охрименко, В. М. Пугач, С. Барсук, М.-Э. Шунэ

НЕКОТОРЫЕ ФИЗИЧЕСКИЕ ИЗМЕРЕНИЯ В ЭКСПЕРИМЕНТЕ LHCB И СИСТЕМА РАДИАЦИОННОГО МОНИТОРИНГА

Эксперимент LHCb, размещенный на Большом адронном коллайдере (LHC), предназначен для изучения редких явлений в распадах b- и c-кварков, чтобы точнее измерить параметры стандартной модели, а также для поиска явлений за ее рамками. Детектор LHCb полностью установлен и введен в эксплуатацию - получены первые данные от pp-столкновений при энергии $E_{\text{с.ц.м.}}$ = 900 ГэВ и $E_{\text{с.ц.м.}}$ = 7 ТэВ. Характеристики эксперимента LHCb позволяют достигать ожидаемых точностей в измерениях углов матрицы Кабибо - Кобаяши - Маскавы, фаз смешивания $B_{d,s}$ -мезонов и угла γ треугольника унитарности. Обсужден поиск сигналов новой физики в b-секторе на примере редкого распада $B_s \to \mu^+\mu^-$, а также изучения спиральности фотона в распаде $B_s^0 \to \varphi\gamma$. Обсуждено измерение уровня радиационных нагрузок и их влияние на работу кремниевой внутренней трековой системы и контроль состояния пучка с помощью системы радиационного мониторинга, разработанной в ИЯИ НАН Украины.

Ключевые слова: эксперимент LHCb, нарушение CP-симметрии, радиационный распад B^0_s-мезона, система радиационного мониторинга.

Received 22.06.11,
revised - 28.07.11.