Vol. 40 (2009) ACTA PHYSICA POLONICA B No 6

PROSPECT OF THE γ CKM ANGLE DETERMINATION FROM $B_d^0 \to D^{*\pm} a_1^{\mp}(1260)$ DECAY PROCESS*

Krzysztof Ciba, Piotr Morawski, Bogdan Muryn
Agnieszka Oblakowska-Mucha, Katarzyna Senderowska

Faculty of Physics and Applied Computer Science
AGH-University of Science and Technology
Al. Mickiewicza 30, 30-059 Kraków, Poland

Grzegorz Polok, Mariusz Witek

H. Niewodniczański Institute of Nuclear Physics PAN
Radzikowskiego 152, 31-342 Kraków, Poland

(Received December 8, 2008; revised version received March 30, 2009; final version received May 18, 2009)

The selection efficiencies and approximate background for the $B_d^0 \to D^{*\pm} a_1^{\mp}(1260)$ mode are determined from studies based on Monte Carlo generated samples. It was found that evaluated annual rate of such decay events makes a hope for a better than at present precision of the CKM unitary triangle angle measurement. Estimated uncertainties depending on value of the γ angle are 10.0 ± 1.1 for $\gamma = 40°$, 7.8 ± 0.3 for $\gamma = 60°$ and finally 7.0 ± 0.2 for $\gamma = 80°$.

PACS numbers: 13.20.He, 12.15.Hh

1. Introduction

Although the CP symmetry braking was observed already in 1964 for the neutral kaon system [1], an origin of this phenomena is still an open question in particle physics. According to the Standard Model this effect is caused by the complex couplings between tree generations of quarks and parametrized by Cabibbo–Kobayashi–Maskawa mixing matrix (CKM) [2]. The decays of B mesons provide excellent opportunity to enhance our knowledge on the CP violation phenomena. In 2001 the first measurements were made at the B-factories by BaBar and Belle collaborations using $B_d \to J/\psi K_s^0$ decays [3, 4]. A magnitude of the CP breaking can be expressed in terms of the CKM unitary triangle [2] because the unitarity condition leads to

* Supported by the Polish Ministry of Science and Higher Education.

relations which are geometrically represented as triangles in the complex plane. The three angles of the most important triangle corresponding to b quark decays, α, β and γ can be determined from the analysis of the specific B decay modes which involve relevant elements of the CKM matrix. So far only β angle has been measured with the precision of about 4%, while uncertainty of α and γ angle measurements still remain large. Here we report on the possible measurement of the $(2\beta+\gamma)$ combination in the forthcoming LHCb experiment at the Large Hadron Collider (LHC) [7, 8]. Due to good precision on β value the measurement of $(2\beta+\gamma)$ can serve as the γ angle determination. Usually the CP braking parameters are extracted from B decays into final states that are CP eigenstates. However, there is a possibility to use decays of the B mesons into final states that are not CP eigenstates. The most common method of extraction of the CP violation parameters in this case is to choose a final state f to which both B_d^0 and $\bar{B}_d^0$ can decay [9, 10]. Because of $B_d^0-\bar{B}_d^0$ mixing, CP violation occurs due to an interference between the amplitudes $B_d^0 \to f$ and $B_d^0 \to \bar{B}_d^0 \to f$. This technique can be employed to a set of four decay modes, $B_d^0 \to D^{*\pm}a_1^{\mp}$, $\bar{B}_d^0 \to D^{*\pm}a_1^{\mp}$. The following subsequent decays have been chosen for the study: $D^{*-} \to (\bar{D}^0 \to K^+\pi^-)\pi^-$, $a_1^+ \to (\rho^0 \to \pi^+\pi^-)\pi^+$ and charge conjugates. Since the decay process follows the simple tree-diagram such type of decay allows a clean extraction of the γ angle. The branching ratios for considered decay processes, taken from [5] are listed in Table I. In further we define $D^{*+}a_1^-$ and $D^{*-}a_1^+$ as f and $\bar{f}$, respectively. The considered $B_d^0 \to f$ and $B_d^0 \to \bar{f}$ are not CP eigenstates, *e.g.*

TABLE I

Branching ratios of decay $B_d^0 \to D^{*\mp}a_1^{\pm}$ (all BR's taken from [5]).

Decay	BR ($\times 10^{-2}$)
$B_d^0 \to D^{*\mp}a_1^{\pm}$	$1.30 \pm 0.27^{(a)}$
$a_1(1260)^{\pm} \to \rho^0\pi^{\pm}$	$60.0^{(b)}$
$\rho^0 \to \pi^+\pi^-$	$100.0^{(c)}$
$D^*(2010)^{\pm} \to D^0\pi^{\pm}$	67.7 ± 0.5
$D^0 \to K^{\pm}\pi^{\mp}$	3.8 ± 0.9
$\mathrm{BR_{tot}} = \prod_i \mathrm{BR}_i$	0.0201 ± 0.0063

(a) BaBar experiment published the measurement of $\mathcal{B}(B_d^0 \to D^{*\mp}a_1^{\pm}) = 1.20 \pm 0.07(\mathrm{stat}) \pm 0.14(\mathrm{syst})\%$, see [6];
(b) lack of uncertainties due to model dependent determination of this branching ratio;
(c) 2π decay mode is dominant due isospin invariance thus other decay modes have small branching fractions (in order of $10^{-5} \div 10^{-3}\%$.)

$$\Gamma(B_d(t) \to f) \neq \Gamma(\bar{B}_d(t) \to \bar{f}) \,, \tag{1}$$
$$\Gamma(B_d(t) \to \bar{f}) \neq \Gamma(\bar{B}_d(t) \to f) \,. \tag{2}$$

The idea of this measurement is very similar to the analysis of $B_d^0 \to D^{*\mp}\pi^{\pm}$ by LHCb [11]. The four decay rates are expressed by the following equations:

$$\Gamma(B_d^0 \to f) = A(t)[(1+|\xi_f|^2) + (1-|\xi_f|^2)\cos(\Delta mt) - 2\mathrm{Im}(\xi_f)\sin(\Delta mt)] \,, \tag{3}$$
$$\Gamma(\bar{B}_d^0 \to f) = A(t)[(1+|\xi_f|^2) - (1-|\xi_f|^2)\cos(\Delta mt) + 2\mathrm{Im}(\xi_f)\sin(\Delta mt)] \,, \tag{4}$$
$$\Gamma(\bar{B}_d^0 \to \bar{f}) = A(t)[(1+|\xi_{\bar{f}}|^2) + (1-|\xi_{\bar{f}}|^2)\cos(\Delta mt) - 2\mathrm{Im}(\xi_{\bar{f}})\sin(\Delta mt)] \,, \tag{5}$$
$$\Gamma(B_d^0 \to \bar{f}) = A(t)[(1+|\xi_{\bar{f}}|^2) - (1-|\xi_{\bar{f}}|^2)\cos(\Delta mt) + 2\mathrm{Im}(\xi_{\bar{f}})\sin(\Delta mt)] \,, \tag{6}$$

where $A(t) = Ne^{-\Gamma t}$, N is the common normalization factor and Δm is the mass difference between heavy and light B^0 mass eigenstates. The ξ_f and its CP conjugate $\xi_{\bar{f}}$ are given by the following formulas:

$$\xi_f = |\xi_f| e^{i(\delta - (2\beta+\gamma))} \,, \tag{7}$$
$$\xi_{\bar{f}} = |\xi_f| e^{i(\delta + (2\beta+\gamma))} \,. \tag{8}$$

Therefore, the imaginary parts can be expressed as

$$\mathrm{Im}(\xi_f) = |\xi_f| * \sin(\delta - (2\beta+\gamma)) \,, \tag{9}$$
$$\mathrm{Im}(\xi_{\bar{f}}) = |\xi_f| * \sin(\delta + (2\beta+\gamma)) \,, \tag{10}$$

where the angle δ is a strong phase shift entering the ξ_f and $\xi_{\bar{f}}$ observables. The decays $B_d^0 \to D^{*\mp} a_1^{\pm}$ proceed via $b \to c\bar{u}d$ and $b \to u\bar{c}d$ amplitudes [12,13]. Assuming that hadronic effects cancel in the ratio of amplitudes the $|\xi_f|$ can be expressed by:

$$|\xi_f| = \frac{|V_{ub}|\,|V_{cd}|}{|V_{cb}|\,|V_{ud}} \,. \tag{11}$$

The measurement relies on a fit of the imaginary parts of ξ_f and $\xi_{\bar{f}}$ observables (Eqs. (7), (8)) to experimentally determined four decay rates (defined in Eqs. (3)–(6)). The absolute values of ξ_f and $\xi_{\bar{f}}$ are customarily evaluated from Eq. (11) using well measured quark transition matrix elements $|\mathrm{V}_{ik}|$. Substituting values for the CKM matrix elements one obtains relatively small value $|\xi_f| = 0.021$ what results in a small value of imaginary part. Therefore, for a precise γ angle evaluation a large number of signal events with a high purity is required. The method for the γ angle measurement presented here can be applied for all neutral B_d^0 meson decays modes $D^{*\mp}h^{\pm}$, where h is a light hadron (π, ρ, a_1).

2. The LHCb detector

The Large Hadron Collider Beauty Experiment for precision measurements of CP violation and rare decays (LHCb) is one of the four experiments at the LHC at CERN, where proton–proton will collide at centre-of-mass energy $\sqrt{s} = 14\,\text{TeV}$. A rich spectrum of B hadrons will be produced due to large production cross section (500 mb) and luminosity of about $2 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$ (10^{12} $b\bar{b}$ pairs per year). The principal goal of LHCb is to look for indirect evidence of new physics in CP violation and rare decays of beauty and charm hadrons. At the centre-of-mass energy of LHC, gluon fusion dominates the $b\bar{b}$ production mechanism and due to a specific features of the gluon–gluon interaction significant part of such events is expected to be produced in the same forward or backward cone, motivating construction of the LHCb detector as a single-arm spectrometer. The main components are the silicon Vertex Locator (VELO), four tracking stations (TT,T1,T2,T3), the magnet, two Ring-Imaging CHerenkov (RICH) counters, Electromagnetic (ECAL) and Hadronic (HCAL) Calorimeters, and finally muon stations. A detailed description of the LHCb detector can be found in [14].

VELO and tracking stations are used for reconstruction of the trajectories of a charged particles providing a precise measurements of track coordinates what assures good reconstruction of primary and secondary vertices. The tracking performance parameters are shown in Table II. Particle identification is provided by the RICH counters ($\pi/K/p$), the Shashlik type ECAL ($e^{\pm}, \gamma$), the iron/scintillating HCAL (hadrons) and the muon system $\mu^{\pm}$ made up of Multi Wire Proportional Chambers. Both electromagnetic and hadron calorimeters have very good energy resolutions. The ECAL for electromagnetic particles has an energy resolution of about $\sigma_E/E = 10\%/\sqrt{E} \oplus 1\%$ while for hadronic particles the HCAL offers an energy resolution $\sigma_E/E = 80\%/\sqrt{E} \oplus 10\%$, where E is expressed in GeV.

TABLE II

The parameters used to emulate the LHCb detector performance.

Parameter	Value
Track reconstruction efficiency $p > 10\,\text{GeV}$	95%
Track momentum resolution $\Delta p/p$	0.4 %
Impact parameter resolution	$14\,\mu m$+$35\,\mu m/p_{\text{T}}$[GeV]
Primary vertex resolution $\sigma_x,\ \sigma_y,\ \sigma_z$	$10\,\mu m$, $10\,\mu m$, $50\,\mu m$
Pion $\rightarrow$ kaon misidentification rate	5%
Kaon identification efficiency	95%

The sophisticated trigger system is used to filter interesting B decay events out of a huge number of inelastic proton–proton interactions. It consists of two main levels, the Level-0 and the HLT (High Level Trigger). The Level-0 is implemented in custom electronics, operates synchronously with the 40 MHz bunch crossing frequency and reduces the event rate down to 1 MHz. The Level-0 selects events with high transverse momentum (p_{T}) object, typically between 2 GeV/c and 4 GeV/c, like electron, muon, hadron or photon, p_{T} being calculated with respect to the beam axis. Due to high mass of the B mesons their decay products have in average larger transverse momenta than particles coming from the events of light quarks production. The HLT is executed asynchronously on a processor farm. It consists of a number of dedicated algorithms for fast reconstruction and selection. The general idea is to confirm the objects that triggered Level-0 decision using information from the tracking system, calorimeters and muon stations. The confirmed tracks are required not to originate from the proton–proton collision vertex as expected for the B meson decay products. In the last stage of HLT the inclusive and exclusive selections of the specific B decay channels are employed. Accepted events are written to storage at the rate of 2000 events/second. Further details of the LHCb trigger system can be found in [15].

3. Emulation of data analysis

The primary goal of the study is to check the feasibility of experimental analysis of the B_d^0 and $\bar{B}_d^0$ decays into $D^{*\mp}a_1^{\pm}$. The study was performed at the physics generator level without usage of the experimental software or data of the LHCb Collaboration. The basic detector effects were emulated using smearing of track and vertex parameters and applying global efficiency factors taken from the published LHCb papers and public notes [7,14]. Such simplified approach has clear limitations since the details of the detector response are not included. However, the legitimacy of the approach has been checked for the decay $B^0 \to D^{*-}\pi^+$ where the predictions were published by LHCb Collaboration and a comparison between the simplified method and full detector simulation was carried out [7].

Both signal and background events have been generated by PYTHIA [16] generator. For the background the sample was restricted to an inclusive production of $b\bar{b}$ pairs[1]. The standard fragmentation to beauty hadrons is followed by their decay chain according to relevant branching ratios. In the case of the signal generation one of the B mesons is forced to decay into required final state. The total samples of 3×10^5 signal events and 96 million background events have been generated. The background sample

[1] The nonelastic interactions without b quarks production is considered by LHCb as entirely suppressed in the off-line analysis stage.

was divided into two halves. One subsample was used to tune the signal to background (S/B) level at the selection stage while the second subsample served as an unbiased measurement of S/B.

The simplified response of the detector was applied as follows. The generated particles inside the sensitive area of the LHCb spectrometer were taken. Their momenta were required to be above $3\,\mathrm{GeV}/c$. The full simulation efficiency [7] of the track reconstruction was used to remove a fraction of charged particles which were not detected. The particle identification was approximated by applying the kaon identification efficiency and pion to kaon misidentification rate. The misidentification of other types of particles like proton, muon and electron was not important for the considered decay and was neglected. The errors on x and y track positions at the interaction point are assigned according to the numbers taken from the full simulation and used to smear the track parameters assuming a Gaussian distribution. The momenta of tracks and the position of the primary vertex are smeared, the first one using the momentum dependent resolution and the second with the expected experimental resolution of $10\,\mu m$ in xy projection plane and $50\,\mu m$ along the z axis (beam axis). The vertex fit procedure based on least square method has been developed to reconstruct secondary vertices. The technical correctness of all implemented ingredients has been carefully checked. As an example the Δz distribution and corresponding pull distribution for the decay vertex of B_d^0 are shown in Fig. 1 (pull variable is defined as the difference between generated and reconstructed z position of the secondary vertex divided by its uncertainty originating from the vertex fit). The pull

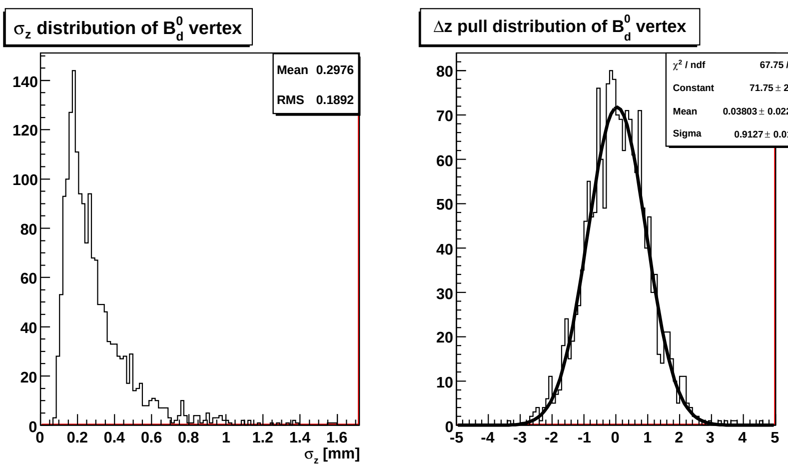

Fig. 1. The distribution of errors on z coordinate and corresponding pull distribution of $B_d^0 \to D^{*\mp} a_1^{\pm}$ vertex as coming from the vertex fit.

distribution is similar to the distribution established from the full simulation and has a Gaussian shape with standard deviation close to unity as expected.

The annual yield in terms of a number of selected signal events $N_{\rm year}$ can be expressed by the following formula:

$$N_{\rm year} = N_{b\bar{b}} \times 2 \times f_q \times D_{\rm BF} \times \varepsilon_{\rm tot}\,, \tag{12}$$

where

- $N_{b\bar{b}} = \int \mathcal{L}(t)dt \times \sigma_{b\bar{b}} = 10^{12}$ is the number of $b\bar{b}$ pairs produced per one year (data taking time = 10^7 seconds) at the average luminosity ($\mathcal{L} = 2 \times 10^{32}$ cm^{-2}s^{-1}) assuming the beauty production cross section $\sigma_{b\bar{b}} = 500\mu$b.
- $2 \times f_q$ is a probability of formation a B_q meson after production of a $\bar{b}$ quark. The factor 2 takes into account the production of both b and $\bar{b}$ quarks.
- $D_{\rm BF} = \prod_i {\rm BF}_i$ is the product of all branching fractions of the decay chain.
- $\varepsilon_{\rm tot}$ contains the efficiencies of the reconstruction and the selection procedure.

The total efficiency is defined as

$$\varepsilon_{\rm tot} = \varepsilon_{\rm geom}\, \varepsilon_{\rm rec}\, \varepsilon_{\rm sel}\, \varepsilon_{\rm trig}\,, \tag{13}$$

where $\varepsilon_{\rm geom}$ is an efficiency related to a geometric acceptance and describes the fraction of generated events with B mesons pointing into sensitive area of the LHCb spectrometer, $\varepsilon_{\rm rec}$ defines a fraction of fully reconstructed signal decays, $\varepsilon_{\rm sel}$ is the fraction of previously reconstructed events satisfying the selection criteria, while $\varepsilon_{\rm trig}$ is the trigger efficiency. The $\varepsilon_{\rm geom} = 34.24\%$ was estimated on the basis of Pythia generated sample and the overall efficiency of the B-decay product reconstruction resulted in $\varepsilon_{\rm rec} = 60.2\%$. The determination of $\varepsilon_{\rm sel}$ is discussed in details in Sec. 3.1. The trigger efficiency cannot be estimated reliably at the level of physics generator study. Therefore, it was assumed to be similar to that of six prong decay events $B_s^0 \to \eta_c\phi$ [7] and taken to be 27%.

3.1. Signal selection

The selection efficiency $\varepsilon_{\rm sel}$ introduced in Eq. (13) contains contributions resulting from the track reconstruction, particle identification and selection cuts. As far as the reconstruction efficiency is related to the LHCb detector performance the selection efficiency is determined in the process of extracting signal out of the background. The selection cuts exploit the features of the B mesons, *i.e.* the relatively long lifetime and high p_{T} of decay products what allows to reduce the background inside the B mass window to an acceptable level.

The crucial variables used to discriminate background are defined as follows:

- IP — Impact Parameter, defined as the minimum distance of the particle trajectory with respect to the interaction vertex;
- secondary vertex quality expressed in terms of the χ^2_{fit} value;
- ΔZ_{PV} — difference between z coordinates of a secondary vertex (SV) and primary vertex (PV);
- momenta and transverse momenta (p_{T}) of the interaction products, p_{T} being calculated with respect to the beam axis;
- $\alpha_{\mathrm{pointing}}$ — the angle between the momentum vector of a B meson and the vector starting in PV position and ending in SV position.

The significance for a given variable is defined as the value divided by its uncertainty, thus in the case of impact parameter it is $\mathrm{IP}/\sigma_{\mathrm{IP}}$, where σ_{IP} stands for impact parameter error. The further requirements reflecting the topology and the kinematic properties of the decay chain (Fig. 2) enable to additionally suppress background originating from the $b\bar{b}$ production.

The event selection will be described for the $B_d^0 \to D^{*-}a_1^+$ decay chain. The analysis starts from an "end", namely going from the selected final decay state containing all final products *i.e.* $K^+\pi^-\pi^-\pi^+\pi^-\pi^+$ to the selection of initial B_d^0 meson through successive reconstruction of all intermediate decay states. The first step is the reconstruction of $\bar{D}^0 \to K^+\pi^-$ decay subprocess.

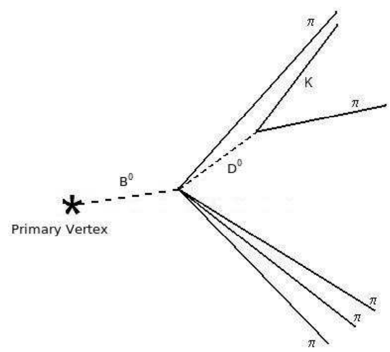

Fig. 2. The topology of the $B_d^0 \to D^{*\mp}a_1^{\pm}$.

The combinations of oppositely charged kaons and pions in the event are used to construct the $\bar{D}^0$ secondary vertex. The $\bar{D}^0$ candidates satisfying criteria developed on the basis of the Monte Carlo signal and background samples (see Table III) are kept. Having selected $\bar{D}^0$ meson one comes to the reconstruction of D^{*-} particle combining previously selected $\bar{D}^0$ with one of the charged pions that did not take part in $\bar{D}^0$ reconstruction. The next step after the D^{*-} particle has been established is a reconstruction of a_1^+. For that purpose one combines three charged pions. The invariant mass of two opposite pions has to be around the nominal mass of ρ^0 and the invariant mass of the three pions system around the a_1^+ mass. Finally, the

TABLE III

The selection cuts for $B_d^0 \to D^{*\pm} a_1^{\mp}(1260)$ and its charge conjugate.

Selection	Value	Efficiency [%]
General cuts		
p_{T} of any charged particle	>50 MeV	97.22
p of any charged particle	>3 GeV	26.63
D^0 related cuts		
IP significance of pion and kaon from D^0	>3.0	99.60
p_{T} of kaon from D^0	>300 MeV	93.81
p_{T} of pion from D^0	>450 MeV	91.38
D^0 mass window	±40 MeV	94.23
χ^2/NDF of D^0 vertex	<9.0	99.77
ΔZ_{PV} significance D^0 vertex	>3.0	97.55
D^* related cuts		
IP of pion from D^* w.r.t. D^0 vertex	<0.2 mm	99.79
D^* mass window around the nominal mass	±40 MeV	94.71
χ^2/NDF of reconstructed D^* vertex	<9.0	99.93
a_1 related cuts		
ρ mass window (any $\pi^+\pi^-$ pair from a_1)	±250 MeV	89.07
a_1 mass window	±500 Mev	91.98
ΔZ_{PV} significance a_1 vertex	>5.0	81.74
χ^2/NDF of a_1 vertex	<9.0	90.74
B^0 related cuts		
B^0 mass window	±80 MeV	99.53
χ^2/NDF of B^0 vertex	<4.0	100.0
$\cos\alpha_{\mathrm{pointing}}$	> 0.9995	99.94
ΔZ_{PV} significance B^0 vertex w.r.t. PV	>5.0	100.0
Total selection efficiency $\varepsilon_{\mathrm{sel}}$		11.91

reconstructed D^{*-} and a_1^+ mesons are used to form B_d^0 meson. The B_d^0 decay vertex is fitted using particles outgoing directly from the decay point *i.e.* pion from D^{*-}, the three pions from a_1^+ and the previously reconstructed $\bar{D}^0$. The final requirements concern a separation of the B_d^0 vertex from primary vertex and the $\alpha_{\rm pointing}$. The specific numbers related to consecutive requirements are summarized in Table III. The two cuts applied on final B^0 meson: *(i)* $\Delta Z_{\rm PV}$ significance B^0 vertex w.r.t. PV and *(ii)* $\alpha_{\rm pointing}$, were tuned to obtain the optimal S/B ratio. For the S/B = 20 calculated in a mass window ± 50 MeV/c^2 around B^0 mass[2], the expected yearly yield was estimated to be 190 k events.

The emulation of the data analysis was done with a number of simplifications. To prove that obtained results are close to those derived from the full detector simulation an additional analysis for similar $B_d^0 \to D^{*\mp}\pi^\pm$ decay process has been carried out and compared with corresponding full analysis of LHCb Collaboration [7]. The yearly yields compared at the same background to signal ratio agreed within 10%.

4. Expected precision of γ angle measurement

A determination of the γ angle precision was done in two steps. Basing on the emulation of signal selection, the annual yield and S/B ratio had to be determined. In the second step the obtained parameters with their uncertainties made up an input to the studied decay model which included the detector efficiencies and resolutions. A toy Monte Carlo technique based on ROOT [17] package has been used. The emulation of the measurement consists of the Monte Carlo sample generation according to distributions corresponding to the decay rates given by four equations (3)–(6). These distributions are not measured directly in the experiment due to distortions caused by the imperfections of the detector and the selection cuts applied. Therefore, one has to construct the probability density function (PDF) which resembles as much as possible the expected distributions originating from the LHCb experimental data. A number of detector effects concerning the proper time resolution, the tagging efficiency (determination of produced flavour *i.e.* B_d^0 or $\bar{B}_d^0$), the wrong tagging rate and the proper time dependent acceptance were included. The tagging efficiency and wrong tagging rate was taken to be 0.45 and 0.3, respectively, the typical values estimated by the LHCb experiment. The standard LHCb curve of proper time dependent acceptance was employed. From this PDF data sample has been generated and then two CP related parameters $\mathrm{Im}(\xi_f)$ and $\mathrm{Im}(\xi_{\bar{f}})$ were fitted with the same PDF. The sum $2\beta + \gamma$ was then determined allowing in turn to calculate γ as the β angle is assumed to be precisely known from other

[2] 50 MeV/c^2 corresponds to 3σ of the Gaussian mass distribution for signal events.

measurements. Since extracted signal is very clean (S/B = 20) the small contribution of background events was neglected in the fit. The precision of the γ determination depends on the factor related to the $\sin(\Delta m t)$ term. For this study the following values have been assumed: $|\xi_f| = 0.021$, $\beta = 23°$, $\delta = 60°$and $\gamma = 40°, 60°$ and $80°$, respectively. For the single generated sample (toy experiment) the parameters uncertainty was calculated by the MINUIT [18] program. To cope with the effects of limited number of events in the CP sensitive region of phase space a large number of toy experiments was performed and an average uncertainty has been evaluated. Such a procedure enables also to check for the possible biases by comparing generated and fitted values. The average uncertainty for the measurement corresponding to 5 years of data collecting was estimated to be $10.0° \pm 1.1°, 7.8° \pm 0.3°$ and $7.0° \pm 0.2°$ for γ values $40°, 60°$ and $80°$, respectively, where the quoted uncertainty is pure statistical one. This statistical uncertainty gets larger with decreasing value of the strong phase δ.

5. Conclusions

The feasibility study of the γ angle of unitarity triangle measurement for the $B_d^0 \to D^{*\mp} a_1^{\pm}$ decays in the LHCb experiment has been performed. The study was based on the fast simulation approach. The simplified emulation of detector response and event selection procedure have been applied to events coming from the PYTHIA generator. The legitimacy of the fast simulation approach was checked for the $B_d^0 \to D^{*\mp} \pi^{\pm}$ decay by comparing the fast simulation and the full simulation results published by LHCb Collaboration. The achieved agreement at the level of 10% proves that the fast simulation method serves very well to estimate both, the rate of expected experimentally events and the background level. The approximated event yield for five years of data taking was used to estimate the precision of the γ angle measurement to be 10.0 ± 1.1 for $\gamma = 40°$, 7.8 ± 0.3 for $\gamma = 60°$ and finally 7.0 ± 0.2 for $\gamma = 80°$. The performed study showed that the attempt for full analysis by LHCb is promising and makes a hope that future experimental analysis of $B_d^0 \to D^{*\mp} a_1^{\pm}$ decay will improve the precision of γ angle measurement.

REFERENCES

[1] J.H. Christenson *et al.*, *Phys. Rev. Lett.* **105**, 1413 (1964).

[2] M. Kobayashi, T. Maskawa, *Progr. Theor. Phys.* **49**, 652 (1973).

[3] [BaBar Collaboration] B. Aubert *et al., Phys. Rev. Lett.* **87**, 091801 (2001).

[4] [Belle Collaboration] K. Abe *et al., Phys. Rev. Lett.* **87**, 091802 (2001).

[5] [Particle Data Group Collaboration] K. Hagiwara *et al., Phys. Rev.* **D66**, 010001 (2002).

[6] B. Aubert *et al.*, SLAC-PUB-9315, `arXiv:hep-ex/0207085`.

[7] [LHCb Collaboration], Technical Design Report, LHCb TDR 9, CERN-LHCC-2003-30 (2003).

[8] R. Fleischer, *Int. J. Mod. Phys.* **A12**, 2459 (1997).

[9] R. Aleksan, I. Dunietz, B. Kayser, F. Le Diberder, *Nucl. Phys.* **B361**, 141 (1991).

[10] R. Aleksan, I. Dunietz, B. Kayser, *Z. Phys.* **C54**, 653 (1992).

[11] J. Rademacker, LHCb public note 2001-153.

[12] P.F. Harrison *et al.*, SLAC-R-0504 (1998).

[13] I. Dunietz, *Phys. Lett.* **B427**, 179 (1998).

[14] [LHCb Collaboration], The LHCb Detector at the LHC 2008, JINST 3 S08005.

[15] [LHCb Collaboration], Technical Design Report, LHCb TDR 10, CERN-LHCC-2003-31 (2003).

[16] T. Sjöstrand, L. Lönnblad, S. Mrenna, P. Skands, "PHYTIA 6.3 Physics and Manual", `hep-ph/0308153`.

[17] R. Brun, F. Rademakers, *Nucl. Instrum. Methods* **A389**, 81 (1991).

[18] F. James, M. Roos, *Comput. Phys. Commun.* **10**, 343 (1975).