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Measurement of the polarization in the decay $B \to J/\psi K^*$

ARGUS Collaboration

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Abstract

Polarization in the exclusive decay $B \to J/\psi K^*$ was measured using the ARGUS detector at the e^+e^- storage ring DORIS II. The ratio of the transverse to the total decay width was found to be $\Gamma_T/\Gamma = 0.03 \pm 0.16 \pm 0.15$. This measurement demonstrates that the $B^0 \to J/\psi K^{*0}$ decay channel can be effectively used for CP violation studies.

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A measurement of the polarization in the $B \to J/\psi K^*$ decay channel is of special interest for CP violation studies [1]. The longitudinally polarized helicity state of the $B^0 \to J/\psi K^{*0}$ decay followed by $K^{*0} \to K_S^0 \pi^0$ is a pure CP eigenstate. If longitudinal polarization dominates, this decay channel can be used as an important complement to the gold plated $B^0 \to J/\psi K_S^0$ decay channel for CP violation measurements [2].

Moreover the polarization measurements of two body $B \to J/\psi K^*$ decays give an important opportunity to test different theoretical approaches. The ratio of the transverse to the total decay width Γ_T/Γ, calculated in the framework of HQET and the BSW model, varies from 0.43 using the standard form factor approach to 0.27 using alternative form factors [3]. A model of Lepage and Brodsky predicts the ratio $\Gamma_T/\Gamma = 0.17$ in the framework of perturbative QCD [4]. The ARGUS study of J/ψ polarization in inclusive $B \to J/\psi X$ decays [5] implied a dominant contribution of the longitudinal polarization.

In this paper we concentrate on a polarization study of the exclusive decay $B \to J/\psi K^*$ in order to separate the pure two vector meson final states, and complement the analysis with a K^* polarization study. The polarization in such two body decays can be measured in the framework of the helicity representation [2], extracting the amount of the transversely polarized K^* and J/ψ mesons from the angular distributions of their decay products.

The analysis is based on data collected using the ARGUS detector at the e^+e^- storage ring DORIS II at DESY. The data sample comprises an integrated luminosity of 246 pb^{-1} on the $\Upsilon(4S)$ resonance and 98 pb^{-1} in the nearby continuum. The number of B mesons in the sample is 418000±19000. The ARGUS detector, its trigger and particle identification capabilities are described in detail elsewhere [6].

Charged particles were identified on the basis of specific ionization in the drift chamber, time-of-flight measurements, energy deposition and shower shape in the electromagnetic calorimeter and, for muons, penetration through absorber to the muon chambers. This information was combined into an overall likelihood ratio [6] for each of the allowed particle hypotheses (e, μ, π, K and p). All hadron hypotheses for which the likelihood ratio exceeds 0.01 were accepted.

Good particle identification and geometrical acceptance were assured by requiring that all particles have a polar angle θ, with respect to the beam axis, within the region $|\cos\theta| < 0.92$ and a momentum larger than 60 MeV/c. All combinations of two photons with an invariant mass between 100 MeV/c^2 and 170 MeV/c^2 were accepted as π^0 candidates. Energetic π^0 mesons, whose daughter photons merge into a single cluster in the electromagnetic calorimeter, were included in the analysis by considering all shower clusters with an energy greater than 800 MeV as π^0 candidates. K_s^0 mesons were reconstructed from their $\pi^+\pi^-$ decay mode. The tracks of the K_s^0 candidates could either form a secondary vertex or come from the main vertex. The invariant $\pi^+\pi^-$ mass of K_s^0 candidates was required to lie within ±30 MeV/c^2 of the nominal K_s^0 mass.

Multihadron events were selected by requiring a total multiplicity $(n_{ch} + n_\gamma/2)$ larger than 5, where n_{ch} is the number of charged particles and n_γ is the number of photons. Lepton pairs from converted photons were not included in n_{ch} but were counted as one photon. QED and continuum backgrounds are further suppressed by requiring the second Fox-Wolfram moment H_2 to be smaller than 0.4. In addition, an event was rejected if the momentum of any charged particle was greater than 3 GeV/c.

Two exclusive B meson decay channels $B^0 \to J/\psi K^{*0}$ and $B^- \to J/\psi K^{*-}$ were studied in this analysis. J/ψ mesons were reconstructed in their leptonic decay modes. In order to increase the J/ψ identification efficiency the lepton pairs were selected requiring one lepton with likelihood ratio larger than 0.7, with

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the second track having only to be consistent with the lepton hypothesis (likelihood ratio larger than 0.01). Lepton momenta were required to be larger than 0.9 GeV/c, which is the kinematical limit for leptons from J/ψ mesons produced in B meson decays. For further analysis a mass-constrained fit was applied to lepton pairs having an invariant mass within ±100 MeV/c^2 of the nominal J/ψ mass. K^* mesons were reconstructed in both isospin combinations of $K\pi$. All $K\pi$ combinations with invariant masses within ±100MeV/c^2 of the nominal K^* mass [7] were accepted as K^* candidates.

B meson candidates were formed from $J/\psi K^*$ combinations having an energy within three standard deviations of the beam energy. A kinematic fit was then applied to the B candidates, constraining their energy to the beam energy. The fit improves the mass resolution by an order of magnitude to about 5.5 MeV/c^2. To avoid multiple counting, only one combination per event was allowed: the candidate with the maximum total probability calculated for the sum of all χ^2 contributions from kinematic fits and particle identification was selected. Only candidates with total probability larger than 1% and a mass larger than 5.17 GeV/c^2 were accepted.

The resulting $J/\psi K^*$ mass spectrum is shown in Fig. 1a. This spectrum was fitted with the sum of a Gaussian describing the signal and a function which parametrizes the background:

$$f(M) = aM\sqrt{1 - M^2/E_{\text{beam}}^2}$$

$$\times \exp(-b(1 - M^2/E_{\text{beam}}^2)),$$

where a and b are free parameters [8]. The width of the Gaussian was fixed from Monte Carlo calculations to σ = 5.5 MeV/c^2 and the B meson mass to its nominal value of M_B = 5.279 GeV/c^2 [9]. The fit procedure resulted in 13.4 $\pm$ 4.2 reconstructed B mesons. In order to estimate the nonresonant $K\pi$ background contribution the same analysis was repeated for ±50 MeV/c^2 wide sidebands immediately below and above the accepted K^* mass region. We obtained 1.0 $\pm$ 1.6 B candidates in the sideband regions (see Fig. 1b). Such a small nonresonant contribution in the sidebands indicates that the nonresonant background under the K^* signal is negligible. It is taken into account as a systematic uncertainty.

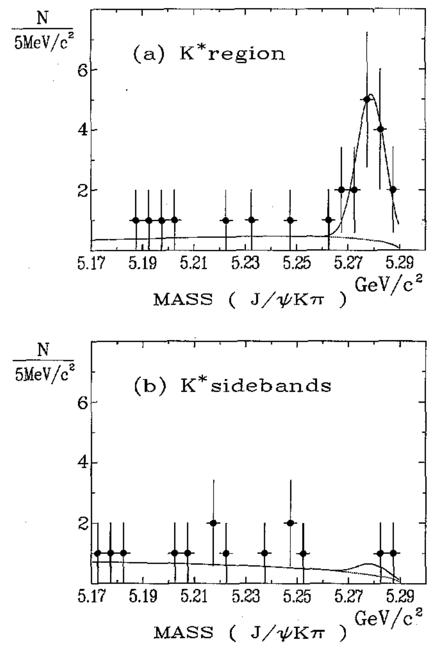

Fig. 1. The invariant mass distribution of $J/\psi K\pi$ combinations (points). Solid lines show the fit results. (a) $K\pi$ invariant mass within ±100 MeV/c^2 of the nominal K^* mass. (b) $K\pi$ invariant mass within left and right sideband regions shifted from the nominal K^* mass by 0.15 GeV/c^2.

J/ψ and K^* combinations with an invariant mass larger than 5.26 GeV/c^2 were used for the angular analysis. The combinatorial background under the B meson signal was estimated to be 1.9 ± 0.7 events and was also included in the systematic uncertainty.

Since the B meson is a pseudoscalar it decays into two vector mesons J/ψ and K^* with three possible final helicity states: $(-1,-1), (0,0), (+1,+1)$. Longitudinally and transversely polarized J/ψ mesons have different $\cos\theta_{J/\psi}$ distributions, where $\theta_{J/\psi}$ is the angle between the J/ψ direction in the rest frame of the B meson and the direction of the positive lepton in the J/ψ rest frame. Similarily the polarization of K^* mesons results in different angular distributions for their decay products. The expected angular distributions for the pure helicity states are [1]:

$$d\Gamma_L/d(\cos\theta_{J/\psi}) = \tfrac{3}{4}\sin^2\theta_{J/\psi},$$

$$d\Gamma_T/d(\cos\theta_{J/\psi}) = \tfrac{3}{8}(1+\cos^2\theta_{J/\psi});$$

$$d\Gamma_L/d(\cos\theta_{K^*}) = \tfrac{3}{2}\cos^2\theta_{K^*},$$

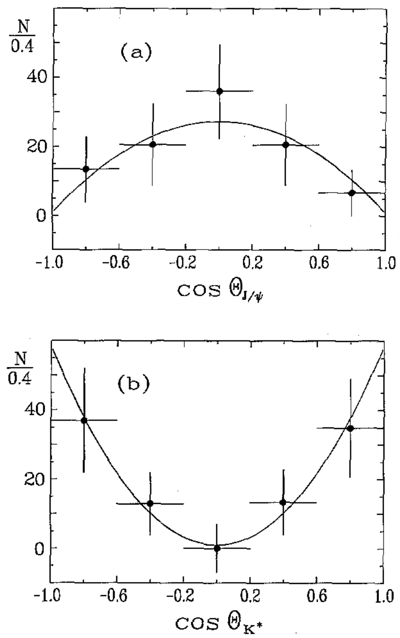

Fig. 2. Angular distributions in the decay $B \to J/\psi K^*$ (points). Solid lines show the fit results. (a) $\cos\theta_{J/\psi}$ angular distributions, where $\theta_{J/\psi}$ is the angle between the J/ψ direction in the rest frame of the B meson and the direction of the positive lepton in the J/ψ rest frame. (b) $\cos\theta_{K^*}$ angular distributions, where θ_{K^*} is the angle between the K^* direction in the rest frame of the B meson and the direction of the K meson in the K^* rest frame.

$$d\Gamma_T/d(\cos\theta_{K^*}) = \tfrac{3}{4}\sin^2\theta_{K^*}.$$

The ratio of the transverse to the total decay width was obtained by fitting the linear combination of these functions to the corresponding experimental angular distributions after boosting to the B meson rest frame.

The acceptance corrected and normalized angular distributions are shown in Fig. 2. The reconstruction efficiencies in different angular intervals were determined from a detailed Monte Carlo simulation and appeared to be flat. Both angular distributions are well described by longitudinally polarized J/ψ and K^* mesons only. A simultaneous fit of both angular distributions gives the ratio $\Gamma_T/\Gamma = 0.03\pm0.16\pm0.15$. The systematic error comes from the efficiency determination (±0.03), the combinatorial background under the B meson signal (±0.12) and the possible $K\pi$ nonresonant background contribution (±0.08). The systematic uncertainties caused by the combinatorial background and the nonresonant $K\pi$ contribution were calculated by varying their polarization from 0 to 1. The obtained result disfavours HQET and the BSW model with standard form factors [3].

In conclusion, we have measured the ratio of the transverse to the total decay width in the decay $B \to J/\psi K^*$ to be $\Gamma_T/\Gamma = 0.03\pm0.16\pm0.15$. Therefore, the balance of $B^0 \to J/\psi K^{*0}$ decays followed by $K^{*0} \to K_S^0\pi^0$ results in a pure CP eigenstate and this decay can be effectively used in future measurements of CP violation [1].

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