Measurement of the Polarization in the Decays $B_d \to J/\psi K^{*0}$ and $B_s \to J/\psi \phi$

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Carithers,[14] D. Carlsmith,[34] A. Castro,[20] Y. Cen,[21] F. Cervelli,[22] H. Y. Chao,[28] J. Chapman,[16] M.-T. Cheng,[28] G. Chiarelli,[22] T. Chikamatsu,[32] C. N. Chiou,[28] L. Christofek,[10] S. Cihangir,[7] A. G. Clark,[22] M. Cobal,[22] M. Contreras,[5] J. Conway,[27] J. Cooper,[7] M. Cordelli,[8] C. Couyoumtzelis,[22] D. Crane,[1] J. D. Cunningham,[3] T. Daniels,[15] F. DeJongh,[7] S. Delchamps,[7] S. Dell'Agnello,[22] M. Dell'Orso,[22] L. Demortier,[26] B. Denby,[22] M. Deninno,[2] P. F. Derwent,[16] T. Devlin,[27] M. Dickson,[25] J. R. Dittmann,[6] S. Donati,[22] R. B. Drucker,[14] A. Dunn,[16] K. Einsweiler,[14] J. E. Elias,[7] R. Ely,[14] E. Engels, Jr.,[23] S. Eno,[5] D. Errede,[10] S. Errede,[10] Q. Fan,[25] B. Farhat,[15] I. Fiori,[2] B. Flaugher,[7] G. W. Foster,[7] M. Franklin,[9] M. Frautschi,[18] J. Freeman,[7] J. Friedman,[15] A. Fry,[29] T. A. Fuess,[1] Y. Fukui,[13] S. Funaki,[32] G. Gagliardi,[22] S. Galeotti,[22] M. Gallinaro,[20] A. F. Garfinkel,[24] S. Geer,[7] D. W. Gerdes,[16] P. Giannetti,[22] N. Giokaris,[26] P. Giromini,[8] L. Gladney,[21] D. Glenzinski,[12] M. Gold,[18] J. Gonzalez,[21] A. Gordon,[9] A. T. Goshaw,[6] K. Goulianos,[26] H. Grassmann,[6] A. Grewal,[21] L. Groer,[27] C. Grosso-Pilcher,[5] C. Haber,[14] S. R. Hahn,[7] R. Hamilton,[9] R. Handler,[34] R. M. Hans,[35] K. Hara,[32] B. Harral,[21] R. M. Harris,[7] S. A. Hauger,[6] J. Hauser,[4] C. Hawk,[27] J. Heinrich,[21] D. Cronin-Hennessy,[6] R. Hollebeek,[21] L. Holloway,[10] A. Hölscher,[11] S. Hong,[16] G. Houk,[21] P. Hu,[23] B. T. Huffman,[23] R. Hughes,[25] P. Hurst,[9] J. Huston,[17] J. Huth,[9] J. Hylen,[7] M. Incagli,[22] J. Incandela,[7] H. Iso,[32] H. Jensen,[7] C. P. Jessop,[9] U. Joshi,[7] R. W. Kadel,[14] E. Kajfasz,[7,*] T. Kamon,[30] T. Kaneko,[32] D. A. Kardelis,[10] H. Kasha,[35] Y. Kato,[19] L. Keeble,[8] R. D. Kennedy,[27] R. Kephart,[7] P. Kesten,[14] D. Kestenbaum,[9] R. M. Keup,[10] H. Keutelian,[7] F. Keyvan,[4] D. H. Kim,[7] H. S. Kim,[11] S. B. Kim,[16] S. H. Kim,[32] Y. K. Kim,[14] L. Kirsch,[3] P. Koehn,[25] K. Kondo,[32] J. Konigsberg,[9] S. Kopp,[5] K. Kordas,[11] W. Koska,[7] E. Kovacs,[7,*] W. Kowald,[6] M. Krasberg,[16] J. Kroll,[7] M. Kruse,[24] S. E. Kuhlmann,[1] E. Kuns,[27] A. T. Laasanen,[24] N. Labanca,[22] S. Lammel,[4] J. I. Lamoureux,[3] T. LeCompte,[10] S. Leone,[22] J. D. Lewis,[7] P. Limon,[7] M. Lindgren,[4] T. M. Liss,[10] N. Lockyer,[21] C. Loomis,[27] O. Long,[21] M. Loreti,[20] E. H. Low,[21] J. Lu,[30] D. Lucchesi,[22] C. B. Luchini,[10] P. Lukens,[7] J. Lys,[14] P. Maas,[34] K. Maeshima,[7] A. Maghakian,[26] P. Maksimovic,[15] M. Mangano,[22] J. Mansour,[17] M. Mariotti,[20] J. P. Marriner,[7] A. Martin,[10] J. A. J. Matthews,[18] R. Mattingly,[15] P. McIntyre,[30] P. Melese,[26] A. Menzione,[22] E. Meschi,[22] G. Michail,[9] S. Mikamo,[13] M. Miller,[5] R. Miller,[17] T. Mimashi,[32] S. Miscetti,[8] M. Mishina,[13] H. Mitsushio,[32] S. Miyashita,[32] Y. Morita,[32] S. Moulding,[26] J. Mueller,[27] A. Mukherjee,[7] T. Muller,[4] P. Musgrave,[11] L. F. Nakae,[29] I. Nakano,[32] C. Nelson,[7] D. Neuberger,[4] C. Newman-Holmes,[7] L. Nodulman,[1] S. Ogawa,[32] S. H. Oh,[6] K. E. Ohl,[35] R. Oishi,[32] T. Okusawa,[19] C. Pagliarone,[22] R. Paoletti,[22] V. Papadimitriou,[31] S. P. Pappas,[35] S. Park,[7] J. Patrick,[7] G. Pauletta,[22] M. Paulini,[14] L. Pescara,[20] M. D. Peters,[14] T. J. Phillips,[6] G. Piacentino,[2] M. Pillai,[25] R. Plunkett,[7] L. Pondrom,[34] N. Produit,[14] J. Proudfoot,[1] F. Ptohos,[9] G. Punzi,[22] K. Ragan,[11] F. Rimondi,[2] L. Ristori,[22] M. Roach-Bellino,[33] W. J. Robertson,[6] T. Rodrigo,[7] J. Romano,[5] L. Rosenson,[15] W. K. Sakumoto,[25] D. Saltzberg,[5] A. Sansoni,[8] V. Scarpine,[30] A. Schindler,[14] P. Schlabach,[9] E. E. Schmidt,[7] M. P. Schmidt,[35] O. Schneider,[14] G. F. Sciacca,[22] A. Scribano,[22] S. Segler,[7] S. Seidel,[18] Y. Seiya,[32] G. Sganos,[11] A. Sgolacchia,[2] M. Shapiro,[14] N. M. Shaw,[24] Q. Shen,[24] P. F. Shepard,[23] M. Shimojima,[31] M. Shochet,[5] J. Siegrist,[29] A. Sill,[31] P. Sinervo,[11] P. Singh,[23] J. Skarha,[12] K. Sliwa,[33] D. A. Smith,[22] F. D. Snider,[12] L. Song,[7] T. Song,[16] J. Spalding,[7] L. Spiegel,[7] P. Sphicas,[15] L. Stanco,[20] J. Steele,[34] A. Stefanini,[22] K. Strahl,[11] J. Strait,[7] D. Stuart,[7] G. Sullivan,[5] K. Sumorok,[15] R. L. Swartz, Jr.,[10] T. Takahashi,[19] K. Takikawa,[32] F. Tartarelli,[22] W. Taylor,[11] P. K. Teng,[28] Y. Teramoto,[19] S. Tether,[15] D. Theriot,[7] J. Thomas,[29] T. L. Thomas,[18] R. Thun,[16] M. Timko,[33] P. Tipton,[25] A. Titov,[26] S. Tkaczyk,[7] K. Tollefson,[25] A. Tollestrup,[7] J. Tonnison,[24] J. F. de Troconiz,[9] J. Tseng,[12] M. Turcotte,[29] N. Turini,[22] N. Uemura,[32] F. Ukegawa,[21] G. Unal,[21] S. van den Brink,[23] S. Vejcik III,[16] R. Vidal,[7] M. Vondracek,[10] D. Vucinic,[15] R. G. Wagner,[1] R. L. Wagner,[7] N. Wainer,[7] R. C. Walker,[25] C. Wang,[6] C. H. 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(Received 9 August 1995)

This Letter reports on measurements of the longitudinal polarization fractions in the decays $B_d \to J/\psi K^{*0}$ and $B_s \to J/\psi \phi$ using data collected with the Collider Detector at Fermilab. B_d mesons are reconstructed through the decay chain $B_d \to J/\psi K^{*0}$, $J/\psi \to \mu^+\mu^-$, $K^{*0} \to K^+\pi^-$. A sample of 65 ± 10 B_d events is used to obtain a longitudinal polarization fraction of $\Gamma_L/\Gamma = 0.65 \pm 0.10(\text{stat}) \pm 0.04(\text{syst})$. B_s mesons are reconstructed through the decay chain $B_s \to J/\psi \phi$, $J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$. A sample of 19 ± 5 B_s events is used to obtain the result $\Gamma_L/\Gamma = 0.56 \pm 0.21(\text{stat})^{+0.02}_{-0.04}(\text{syst})$.

PACS numbers: 13.25.Hw, 13.88.+e

This Letter reports on measurements of the longitudinal polarization fractions Γ_L/Γ in the pseudoscalar-to-vector-vector decays $B_d \to J/\psi K^{*0}$ and $B_s \to J/\psi \phi$ performed by the Collider Detector at Fermilab (CDF) collaboration. Interest in the decay $B_d \to J/\psi K^{*0}$ was originally stimulated by its potential use in *CP* violation studies in e^+e^- colliders [1]. In addition, a measurement of Γ_L/Γ can be used to test theoretical predictions that depend on the factorization hypothesis [2]. In particular, the standard factorization methods are unable to reproduce simultaneously the large measured value of Γ_L/Γ in $B_d \to J/\psi K^{*0}$ [3,4] and the small value of the ratio of branching ratios, $R = \Gamma(B \to J/\psi K^*)/\Gamma(B \to J/\psi K)$ [5]. Recent theoretical efforts to reproduce the experimental results have included several schemes of modifying the form factors or even relaxing the factorization assumption [6]. They have met with varying degrees of success, but all call for more precise measurements of Γ_L/Γ and related quantities. Factorization can also be tested in the decay $B_s \to J/\psi\,\phi$. The longitudinal polarization fraction can be used as an input to a determination of $\Delta\Gamma$ in the B_s system, given sufficient statistics [7], where $\Delta\Gamma$ is the difference in the widths of the B_s states.

Using data collected in 1992–93 at the Fermilab Tevatron, B_d mesons have been reconstructed through the decay chain $B_d \to J/\psi\,K^{*0}$, $J/\psi \to \mu^+\mu^-$, $K^{*0} \to K^+\pi^-$ [8]. The data set consists of 19 pb^{-1} of $\overline{p}p$ collisions at $\sqrt{s} = 1.8$ TeV. The CDF detector has been described in detail elsewhere [9]. The data sample was collected using dimuon triggers in the CDF three-level trigger system. Two tracks are required in the muon chambers at level 1. The trigger efficiency for a muon at level 1 rises from 50% at $p_T = 1.6$ GeV/c to 90% at $p_T = 3.1$ GeV/c with a plateau of 94%, where p_T is the momentum transverse to the beam. The tracks must be separated by at least 0.09 rad in ϕ [10]. The level 2 trigger requires that at least one of the muon tracks is matched in ϕ to a track found by the central fast tracker (CFT), a hardware processor. The efficiency for finding a track with the CFT rises from 50% at $p_T = 2.65$ GeV/c to 90% at $p_T = 3.1$ GeV/c and reaches a plateau of 93%. The level 3 trigger requires a pair of oppositely charged muons with an invariant mass between 2.8 and 3.4 GeV/c^2, using on-line track reconstruction software.

Additional off-line requirements are placed on the muons in order to isolate the J/ψ signal and minimize biases due to trigger thresholds. Both muons are required to have a transverse momentum greater than 1.8 GeV/c, and at least one must have a transverse momentum greater than 2.5 GeV/c. The invariant mass of the muon pair is calculated constraining the muons to come from a common vertex. After all of the above requirements are applied, there are approximately 54 000 J/ψ candidate events with a signal width (σ) of about 16 MeV/c^2, above a background of 7000 events.

Muon pairs within 80 MeV/c^2 of the J/ψ mass [11] are combined with other charged particles to search for B_d mesons. Pairs of oppositely charged particles, each with transverse momentum greater than 500 MeV/c, are considered. The K-π^- particle assignment with invariant mass closest to the K^{*0} mass is used. K^{*0} candidates within 80 MeV/c^2 of the mass of the K^{*0} are retained. All of the B decay products are constrained to come from a common secondary vertex, the muon pair is mass constrained to the J/ψ mass, and the momentum of the B_d candidate is constrained to point from the primary vertex to the secondary vertex in the r-ϕ plane. The combined confidence level from the constrained fit is required to be greater than 1%. The primary vertex position is approximated by the mean beam position, determined run by run using information from the silicon vertex detector [9] and averaging over many events. The transverse profile of the beam is circular and has a σ of $\sim$40 μm.

Additional requirements are made to reduce combinatoric backgrounds. The proper decay distance of the B_d candidate must be greater than 100 μm, the transverse momentum of the B_d candidate must be greater than 8.0 GeV/c, and the transverse momentum of the K^{*0} candidate must be greater than 2.0 GeV/c. The B_d candidate is also required to carry more than half of the total observable momentum within an η-ϕ cone of radius 1.0 around it. Reflections from B_s decay are suppressed by reconstructing the events as $J/\psi\,\phi$, $\phi \to K^+K^-$, and removing events with a K^+K^- mass within 10 MeV/c^2 of the ϕ and a $J/\psi\,\phi$ mass within 30 MeV/c^2 of the B_s. The resulting $J/\psi\,K^{*0}$ mass distribution is shown in Fig. 1. A binned maximum-likelihood fit by a Gaussian plus a flat background yields 65 $\pm$ 10 events.

The decay distribution for $B_d \to J/\psi\,K^{*0}$, $J/\psi \to \mu^+\mu^-$, $K^{*0} \to K^+\pi^-$ can be written as (e.g., see Ref. [12])

$$\frac{d^2\Gamma}{d\cos\theta_{K^*}\,d\cos\theta_\psi} \propto \frac{1}{4}\sin^2\theta_{K^*}(1 + \cos^2\theta_\psi)\frac{\Gamma_T}{\Gamma} + \cos^2\theta_{K^*}\sin^2\theta_\psi\frac{\Gamma_L}{\Gamma},$$

where the helicity angle θ_{K^*} is the decay angle of the kaon in the K^{*0} rest frame with respect to the K^{*0} direction

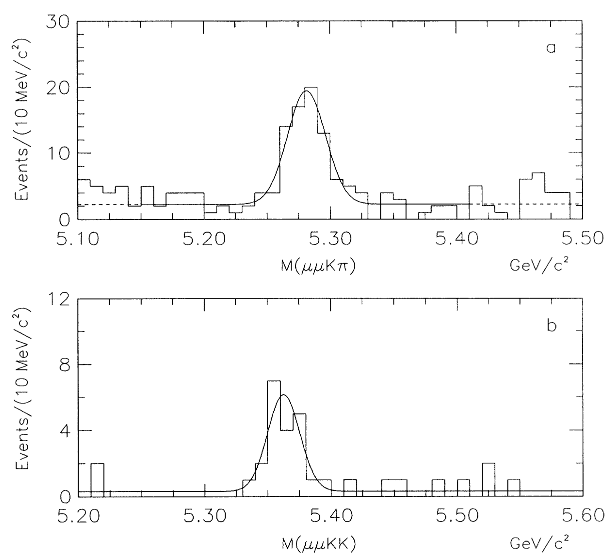

FIG. 1. Invariant mass distributions for (a) $B_d \to J/\psi\,K^{*0}$ and (b) $B_s \to J/\psi\,\phi$. The curves are binned-likelihood fits by a Gaussian plus a flat background. The regions with mass below 5.15 GeV/c^2 or above 5.40 GeV/c^2 in (a), where B decays with either a missing or an extra pion can contribute (dashed line), are excluded from the fit. In (a) there are 65 $\pm$ 10 signal events, and the peak has a width (σ) of 15 $\pm$ 3 MeV/c^2. In (b) there are 19 $\pm$ 5 signal events, and the peak has a width (σ) of 13 $\pm$ 3 MeV/c^2.

in the B rest frame. Similarly, θ_ψ is the decay angle of the muon in the J/ψ rest frame with respect to the J/ψ direction in the B rest frame. The above expression has been integrated over the angle ϕ between the J/ψ and K^{*0} decay planes. The first and second terms represent the transverse and longitudinal helicity states, respectively. The transverse and longitudinal polarization fractions sum to 1.

The polarization is measured using a likelihood function that includes the two-dimensional decay distribution, a term for the background, and acceptance corrections. The background distribution is taken to be unpolarized as determined from a fit to events in the sidebands around the B_d mass. The acceptances are derived from Monte Carlo methods. The B meson p_T distribution is generated according to a fit to the measured differential B meson cross section [13]. The Monte Carlo events are passed through a simulation of the CDF detector and reconstructed in the same way as the data events.

The signal region for the helicity angle analysis is defined as $|m_{\mu\mu K\pi} - m_B| < 30$ MeV/c^2. The result of the unbinned likelihood fit to the data is $\Gamma_L/\Gamma = 0.65 \pm 0.10$ (statistical error only). The result, projected onto background-subtracted, acceptance-corrected plots of the data, is shown in Fig. 2. No particle identification information is used, and therefore the chosen K-π assignment can be incorrect. The percentage of misassigned K and π masses varies from $(4.3 \pm 0.3)\%$ for longitudinal polarization events up to $(6.6 \pm 0.4)\%$ for transverse polarization events, as determined from Monte Carlo

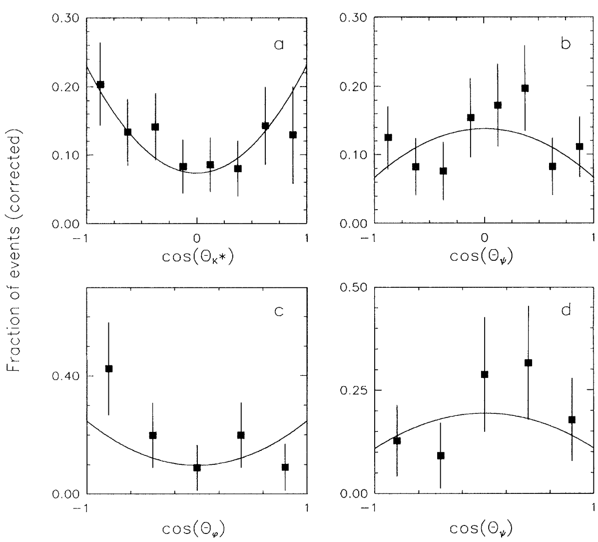

FIG. 2. Background-subtracted and acceptance-corrected helicity angle distributions for the decays $B_d \to J^-/\psi K^{*0}$ [(a) K^{*0} and (b) J/ψ], and $B_s \to J/\psi\, \phi$ [(c) ϕ and (d) J^-/ψ]. The solid curves represent projections of the two-dimensional fits onto the appropriate variable for longitudinal polarization fractions of $\Gamma_L/\Gamma = 0.65$ for B_d and $\Gamma_L/\Gamma = 0.56$ for B_s.

methods. The events with incorrect K-π assignments produce a systematic, negative shift in the fitted value of 0.041, which is independent of the value of the polarization. The result given above has been corrected for this shift.

The misassignment of the K and π masses is the largest source of systematic uncertainty. This uncertainty is determined from a comparison of Monte Carlo simulations and data to be ± 0.028 on Γ_L/Γ. Possible polarization of the background is also a large source of systematic uncertainty. Data from the B_d mass sidebands are used to determine the polarization of the background, which is found to be consistent with an unpolarized distribution. The helicity amplitude used for the background in the likelihood function is varied from its default, unpolarized, value by the uncertainty on the sideband fit to obtain a systematic uncertainty of ± 0.024. The signal-to-background ratio used in the fit is varied to obtain a systematic uncertainty of ± 0.014. Nonresonant decays of the type $B_d \to J/\psi\, K^+\pi^-$ can contribute to the signal region. Fitting data from the mass sidebands of the K^{*0} no events are seen; however, as many as three are allowed by the one σ upper error. Three nonresonant events are added to the fit using both a longitudinal and transverse polarization. A systematic uncertainty of $^{+0.013}_{-0.011}$ is assigned. Variations of the input B meson p_T spectrum are used to assign a systematic uncertainty of $^{+0.011}_{-0.018}$. Systematic uncertainties from the trigger model are less than 0.010. All of the systematic uncertainties are summed in quadrature to obtain the result $\Gamma_L/\Gamma = 0.65 \pm 0.10(\text{stat}) \pm 0.04(\text{syst})$.

The method used to obtain Γ_L/Γ in the decay $B_d \to J/\psi\, K^{*0}$ is also applied to the decay $B_s \to J/\psi\, \phi$. The selection of the data sample, the requirements on the J/ψ and on the additional particles, plus the confidence level cut on the B vertex are all unchanged from those used for the $B_d \to J/\psi\, K^{*0}$ analysis. The transverse momentum of the ϕ candidate must be greater than 2.0 GeV/c, and the reconstructed K^+K^- mass must be within 10 MeV/c^2 of the mass of the ϕ. The transverse momentum of the B_s candidate must be greater than 6.0 GeV/c, and the proper decay length of the B_s candidate must be greater than 50 μm [14]. The resulting mass distribution is shown in Fig. 1. A binned maximum likelihood fit by a Gaussian plus a flat background yields 19 ± 5 events.

The polarization in $B_s \to J/\psi\, \phi$ is determined with the same likelihood function used for $B_d \to J/\psi\, K^{*0}$. The result of the unbinned likelihood fit to the data is $\Gamma_L/\Gamma = 0.56 \pm 0.21(\text{stat})^{+0.02}_{-0.04}(\text{syst})$. The result, projected onto background-subtracted, acceptance-corrected plots of the data, is shown in Fig. 2. The systematic studies carried out for $B_d \to J/\psi\, K^{*0}$ are repeated for $B_s \to J/\psi\, \phi$, except that nonresonant events are neglected, and the background amplitude is varied over all polarization values. The decay $\phi \to K^+K^-$ is free of particle misassignment problems. This is the first measurement of Γ_L/Γ in the decay $B_s \to J/\psi\, \phi$.

In conclusion, a measurement of the longitudinal polarization fraction $\Gamma_L/\Gamma = 0.65 \pm 0.10(\mathrm{stat}) \pm 0.04(\mathrm{syst})$, in the decay $B_d \rightarrow J/\psi K^{*0}$ from a sample of 65 ± 10 events is presented. Combining this result with those from ARGUS, $\Gamma_L/\Gamma = 0.97 \pm 0.16 \pm 0.15$ [3], and CLEO, $\Gamma_L/\Gamma = 0.80 \pm 0.08 \pm 0.05$ [4], yields a world average of $\Gamma_L/\Gamma = 0.74 \pm 0.07$ [15]. The lower value of Γ_L/Γ presented in this Letter, compared to the ARGUS and CLEO results, suggests that the $B_d \rightarrow J/\psi K^{*0}$ decay mode may be more difficult to use for *CP* violation studies than previously believed. In addition, this lower value is easier to accommodate within the factorization assumption. Further measurements are needed to understand fully the limitations of factorization. The first measurement of the longitudinal polarization fraction, $\Gamma_L/\Gamma = 0.56 \pm 0.21(\mathrm{stat})^{+0.02}_{-0.04}(\mathrm{syst})$, in the decay $B_s \rightarrow J/\psi\, \phi$ is also presented.

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Science and Culture of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; and the A. P. Sloan Foundation.

*Visitor.

[1] If the decay $B_d \rightarrow J/\psi K^{*0}$, $K^{*0} \rightarrow K^0\pi^0$, is a *CP* eigenstate it can be used to study *CP* violation in the same manner as $B_d \rightarrow J/\psi K_s$. The final state will be a *CP* eigenstate if the decay is longitudinally polarized. If both *CP* states contribute the observed asymmetry is diluted, but the *CP* asymmetry can still be extracted. See, for example, I. Dunietz *et al.*, Phys. Rev. D **43**, 2193 (1991).

[2] The factorization hypothesis assumes that the decay amplitude can be described as the product of two independent hadronic currents. See, for example, M. Bauer, B. Stech, and M. Wirbel, Z. Phys. C **34**, 103 (1987); M. Wirbel, B. Stech, and M. Bauer, Z. Phys. C **29**, 637 (1985).

[3] H. Albrecht *et al.*, Phys. Lett. B **340**, 217 (1994).

[4] M. S. Alam *et al.*, Phys. Rev. D **50**, 43 (1994).

[5] M. Gourdin, A. N. Kamal, and X. Y. Pham, Phys. Rev. Lett. **73**, 3355 (1994); R. Aleksan *et al.*, in *Proceedings of the 1st Arctic Workshop on Future Physics and Accelerators, Saariselka, Finland, 1994* (LPTHE Report No. Orsay-94/105 hep-ph/941222).

[6] Hai-Yang Cheng and B. Tseng, Phys. Rev. D **51**, 6259 (1994); M. Gourdin, Y. Y. Keum, and X. Y. Pham, Report No. PAR/LPTHE/95-01, hep-ph/9501257; C. E. Carlson and J. Milana, Report No. WM-94-110, hep-ph/9409261; A. N. Kamal and A. B. Santra, Alberta Report No. Thy-31-94, hep-ph/9501221.

[7] I. Dunietz, Report No. FERMILAB-PUB-94/361-T, hep-ph/9501287.

[8] In this paper references to a specific charge state imply the charge-conjugate state as well.

[9] F. Abe *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **271**, 387 (1988), and references therein; D. Amidei *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **350**, 73 (1994).

[10] In CDF the positive z axis lies along the proton direction, r is the radius from this axis, θ is the polar angle, and ϕ is the azimuthal angle. The pseudorapidity η is defined as $-\ln[\tan(\theta/2)]$.

[11] Particle Data Group, L. Montanet *et al.*, Phys. Rev. D **50**, 1173 (1994).

[12] G. Kramer and W. F. Palmer, Phys. Rev. D **46**, 2969 (1992); G. Kramer and W. F. Palmer, Phys. Lett. B **279**, 181 (1992).

[13] F. Abe *et al.*, Phys. Rev. Lett. **75**, 1451 (1995).

[14] The requirements placed on the B_s candidates are less restrictive than those applied to the B_d candidates. The ϕ resonance is significantly narrower than the K^{*0} resonance, thus a smaller mass range is used for the ϕ candidates, resulting in less combinatoric background.

[15] The uncertainty on the polarization obtained from a fixed number of events is a function of the value of the polarization. This dependence must be accounted for when calculating the world average. In the result given here the approximation has been made that the systematic uncertainties are independent of the polarization.