Measurement of $B^0\bar{B}^0$ Mixing at the Fermilab Tevatron Collider

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The $B^0\bar{B}^0$ average mixing parameter χ has been extracted from $e\mu$ and ee events produced in $p\bar{p}$ collisions at $\sqrt{s}=1.8$ TeV. In a sample of 900 $e\mu$ events, the like-sign to opposite-sign charge ratio R is measured to be $0.556\pm0.048(\text{stat})^{+0.035}_{-0.042}(\text{syst})$. In the absence of mixing, the expected value of R would be $0.23+0.06$. The corresponding number for 212 ee events is $0.573\pm0.116(\text{stat})\pm0.047(\text{syst})$ with an expected nonmixing value of 0.24 ± 0.07. The observed excess in R leads to a combined determination of $\chi=0.176\pm0.031(\text{stat+syst})\pm0.032(\text{model})$, where the last uncertainty is due to Monte Carlo modeling.

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The phenomenon of mixing, in which a neutral meson transforms into its antiparticle via flavor-changing weak interactions, can provide constraints on the elements of the Cabbibo-Kobayashi-Maskawa matrix. Early evidence of $B^0\bar{B}^0$ mixing was observed at the CERN $p\bar{p}$ collider [1] and at e^+e^- colliders [2,3]. Recent measurements have been made at CERN [4]. We report a measurement of $B^0\bar{B}^0$ mixing by the CDF (Collider Detector at Fermilab) Collaboration at the Tevatron Collider.

Neutral B mesons $B_d^0(\bar{b}d)$ and $B_s^0(\bar{b}s)$ may be produced in the reaction $p\bar{p}\to b\bar{b}\to B\bar{B}+X$, where B ($\bar{B}$) refers to all $\bar{b}$ (b) flavored hadrons. In the absence of mixing, the direct semileptonic decay of a $B\bar{B}$ pair results in a pair of leptons with opposite charges. The B^0 or $\bar{B}^0$ meson may undergo mixing, $B^0\to\bar{B}^0$ or vice versa, and subsequently decay semileptonically, resulting in a like-sign pair. The magnitude of mixing is determined from the relative rate of like-sign dilepton pairs,

$$R=[N(l^+l^+)+N(l^-l^-)]/N(l^+l^-)\,,$$

where l can be an e, μ, or τ lepton. The results in this Letter are based on $e\mu$ and ee events. The probability of $B^0\bar{B}^0$ mixing can be expressed as

$$\chi=\frac{\text{prob}(b\to\bar{B}^0\to B^0\to l^+)}{\text{prob}(b\to l^\pm)}\,,$$

where the leptons can come from both direct and sequential B decays and the denominator includes all possible hadrons formed with the b quark. We determine χ using our measured value of R and a Monte Carlo calculation of the contribution from other processes.

The CDF has been described in detail elsewhere [5,6]. The $e\mu$ and ee samples were collected with dilepton triggers. The integrated luminosity for the $e\mu$ (ee) trigger is 2.7 pb^{-1} (3.7 pb^{-1}). In the data analysis, electrons are required to have $E_T\geq5$ GeV, and muons $P_T\geq3$ GeV/c. Lepton selection criteria, described in detail in Ref. [6], are applied to both the $e\mu$ and ee candidate events in order to reject hadrons.

After lepton selections, there remain sources of dileptons unrelated to $B^0\bar{B}^0$ mixing. The decays of a single B hadron via the chain $b\to cl\nu$ followed by $c\to sl\nu$ always result in opposite-sign dileptons, kinematically restricted to a low dilepton invariant mass M_{ll}. We remove this background by excluding events in the region $M_{ll}<5.0$ GeV/c^2 for both like-sign and opposite-sign ee and $e\mu$ pairs. In addition, the decays $J/\psi\to e^+e^-$ and $\Upsilon\to e^+e^-$ are a background to mixing in the ee channel. The invariant-mass cut below 5.0 GeV/c^2 removes the former, and excluding the region $8.0<M_{ee}<10.8$ GeV/c^2 removes the latter. After these cuts, there are 346 like-sign and 554 opposite-sign $e\mu$ events, composed of 181 $e^+\mu^+$, 165 $e^-\mu^-$, 290 $e^-\mu^+$, and 264 $e^+\mu^-$ events, and 78 like-sign and 134 opposite-sign ee events. Remaining backgrounds in our determination of R are removed by background subtraction.

To determine the background fraction for the $e\mu$ events, we use the fact that the $e\mu$ events are a subset of an inclusive electron sample. Even after selection cuts, such a sample will contain fake as well as real leptons. In our detector we expect events with a fake muon to be the dominant background in the $e\mu$-event candidates. The amount of real-e, fake-μ and fake-e, fake-μ backgrounds is given by the product of the number of tracks in the inclusive electron events and the fake-μ-per-track rate F_μ. Fake-e, real-μ events are a subset of all fake-electron events, and therefore given by the number of tracks in fake-electron events times the real-μ-per-track rate R_μ.

Experimentally we determine f_μ ($=F_\mu+R_\mu$), the probability that a track is identified as a muon. The product of f_μ and the number of tracks in an inclusive electron sample includes all backgrounds above together with an extra term. This term, which arises from R_μ times the number of tracks in the real electron events, contributes to an overestimate of the background and will be discussed later. The quantity f_μ is obtained from a sample of 278 000 events collected with a minimum-bias trigger. Fake-electron events arising from a low E_T^e inclusive electron trigger are expected to have a rate of heavy-quark production similar to events from the minimum-bias trigger. Thus the probability of real muon production is similar in events from these two triggers. We define m tracks as those tracks which satisfy muon tracking requirements and point to the muon chambers. Of the 2959 m tracks in the minimum-bias sample, 8 satisfy all muon criteria including the muon chamber requirements [6], resulting in a rate of muon candidates per m track $f_\mu = 0.27\%$.

We do not have an inclusive electron sample collected with $E_T^e \geq 5$ GeV, and therefore determine the $e\mu$ background fraction from two samples, collected with trigger E_T^e thresholds of 7 GeV (prescaled) and 12 GeV, with event overlap of less than 5%. In these samples there are 1324 and 2897 m tracks, respectively, excluding tracks associated with electron candidates. The product of these numbers and our measured f_μ, given in the third column of Table I, represents an upper limit on the number of events in which one or both leptons is misidentified. The background fraction (Table I, fifth column) is independent of the electron E_T threshold, and we therefore take it to be $(19 \pm 9)\%$ in the $e\mu$ sample. This figure includes both statistical and systematic uncertainties, described below.

The above-mentioned method for determining the background fraction requires that the properties of m tracks in minimum-bias events be similar to those in electron candidate events. The K/π ratio is a primary source of systematic error, since a difference between the two samples could change the rate of muons per charged track. In Monte Carlo simulation studies of fake muons, in which the K/π ratio is varied over the range 0.12 to 0.36 [7], the value of f_μ changes by less than 15%. In similar studies, f_μ changes by 20% due to different track P_T over the range $3 \leq P_T \leq 12$ GeV/c. These variations are included in our systematic uncertainty. In addition, a comparison of qualities of muon candidates in minimum-bias events and in a J/ψ sample shows that a large fraction of candidates in the minimum-bias sample is background. Thus the overestimate of the background mentioned earlier is small compared to the 47% uncertainty on the background fraction.

TABLE I. Background estimation using inclusive electron samples.

E_T^e (GeV)	N (tracks)	N (fake $e\mu$ expected)	N ($e\mu$ observed)	Background
≥ 7	1324	3.6 ± 1.6	19	$(19 \pm 9)\%$
≥ 12	2897	7.8 ± 3.5	44	$(18 \pm 8)\%$

For the inclusive electron sample (after a 5-GeV/c^2 mass cut), the ratio of like-sign to opposite-sign electron m-track pairs is 0.95 ± 0.06, consistent with no sign correlation. The background fraction of $(19 \pm 9)\%$ therefore corresponds to 86 like-sign and 86 opposite-sign pairs in the 900 $e\mu$ events, resulting in a background-subtracted sample of 260 like-sign and 468 opposite-sign events. From this we obtain

$$R(e\mu) = 0.556 \pm 0.048(\text{stat})^{+0.035}_{-0.042}(\text{syst}),$$

where the systematic uncertainty is calculated by varying simultaneously the numbers of like-sign and opposite-sign background events by 1 standard deviation.

For the ee events, the backgrounds which remain after the invariant-mass requirements are due to misidentified hadrons, photon conversions and Dalitz pairs, and Drell-Yan production. We determine the background due to misidentified hadrons by comparing the behavior of the hadronic to electromagnetic energy ratio in our data to two other samples; one of pure electrons, and one of hadrons which satisfy nearly all electron criteria. The first is obtained from J/ψ decay, and the second consists of electron candidates which display large mismatches between electromagnetic shower position and the location of the track extrapolated to the calorimeter. Such a mismatch is typical of the spatial proximity of charged and neutral pions. A total of 27.1 ± 9.2 events in the ee sample contain a misidentified hadron.

To reject electrons produced in photon conversions and Dalitz decays, we pair each electron with tracks of the opposite charge within a polar angle $\Delta\theta < 5°$. If the point at which the tracks are parallel is within the radius at which photons are likely to convert and their separation there is less than 0.5 cm, then the event is rejected. Dalitz pairs are also rejected by this criterion. We do not reconstruct tracks with $P_T \lesssim 0.4$ GeV/c [8], therefore conversion pairs in which one electron has low P_T are not rejected by this method. Based on a Monte Carlo calculation, the number of conversion electrons remaining due to this inefficiency is 19 ± 14 events.

Drell-Yan events in our sample are distinguished by an opposite-sign electron pair with a lack of nearby energy deposition, in contrast to electrons associated with B decay. We define an isolation variable E_T^{iso} as the transverse energy deposited in the annulus between $r = (\Delta\eta^2 + \Delta\phi^2)^{1/2} = 0.4$ and $r = 0.7$ around the electron [6]. This variable is independent of the electron P_T. The amount of background from the Drell-Yan processes in the ee sample is determined by fitting the E_T^{iso} distribution of all opposite-sign pairs with a weighted sum of the E_T^{iso} behavior of Drell-Yan dielectrons and that of our like-sign pairs, which are free of any Drell-Yan contribution. A sample of $Z^0 \to e^+e^-$ [9] is used to measure the E_T^{iso} dependence of Drell-Yan dielectrons. After rejecting events in which both electrons do not satisfy $E_T^{\text{iso}} > 2.4$ GeV, the remaining Drell-Yan background in our opposite-sign ee sample is 15.4 ± 4.6 events.

We observed no sign correlation in the above background events. After removing these backgrounds, we obtain 55 like-sign and 96 opposite-sign ee events, and $R(ee)=0.573\pm0.116(\text{stat})\pm0.047(\text{syst})$.

In order to extract the average $B^0\bar{B}^0$ mixing parameter χ from the observed values of R, we must account for processes unrelated to mixing which contribute to R. The dominant process is the semileptonic decay of one b and the sequential decay $b\to c\to l$ of the other, resulting in like-sign dilepton events. The ratio of sequential decays (N_s) to first-generation decays (N_f) for both dilepton samples is $N_s/N_f=0.25\pm0.06$, determined using the Monte Carlo program ISAJET [10] together with a full detector simulation. Contributions from high-order processes, such as gluon splitting, are significantly reduced by our kinematic cuts. After the cuts, distributions for variables sensitive to higher-order processes, such as $P_T(e\mu)$, are well reproduced by the Monte Carlo model. The uncertainties on N_s/N_f in the model are due to b- and c-quark semileptonic branching ratios obtained from Ref. [11] (15%), b fragmentation (10%), and $b\bar{b}$ correlations due to higher-order processes (10%). A smaller source of dileptons is the semileptonic decay of $c\bar{c}$ pairs. The fraction of these events is $N_c/N_f=0.07\pm0.07$ ($e\mu$) and 0.02 ± 0.02 (ee), where the difference is mainly due to P_T thresholds. We assign a 100% error to the ratio of $c\bar{c}$ and $b\bar{b}$ production cross sections from ISAJET, which gives a 100% error on the fraction N_c/N_f.

The average $B^0\bar{B}^0$ mixing parameter χ is related to R by

$$R=\frac{2\chi(1-\chi)+[(1-\chi)^2+\chi^2]N_s/N_f}{[(1-\chi)^2+\chi^2]+2\chi(1-\chi)N_s/N_f+N_c/N_f}\,.$$

In the absence of mixing, the Monte Carlo prediction would be $R(e\mu)=0.23\pm0.06$ and $R(ee)=0.24\pm0.07$, both inconsistent with the observed values. From our observed values of R, we obtain

$$\chi(e\mu)=0.179\pm0.027(\text{stat})\pm0.022(\text{syst})\pm0.032(\text{model})$$

and

$$\chi(ee)=0.172\pm0.060(\text{stat})\pm0.024(\text{syst})\pm0.026(\text{model})\,.$$

The combined value is $\chi=0.176\pm0.031(\text{stat+syst})\pm0.032(\text{model})$, where the uncorrelated statistical and systematic uncertainties have been combined, and the Monte Carlo model uncertainty is treated as common. The asymmetry of the systematic uncertainty in $R(e\mu)$ leads to negligible asymmetry in $\chi(e\mu)$. The muon P_T spectra for the data and for the Monte Carlo model with the determined mixing and background are shown in Fig. 1, for like-sign and opposite-sign $e\mu$ events separately. Similar results are obtained for the ee events.

The value of χ determined above is averaged over all B mesons and baryons that may be produced in an event. These include neutral mesons such as B_d^0 and B_s^0 which transform into their own antiparticles via mixing and charged B mesons and baryons which do not undergo mixing. To separate the mixing parameters for B_d^0 and B_s^0 in the expression

$$\chi=P_d\chi_d+P_s\chi_s\,,$$

where

$$\chi_{d(s)}\equiv\frac{N(B^0_{d(s)}\to\bar{B}^0_{d(s)})}{N(B^0_{d(s)}\to B^0_{d(s)})+N(B^0_{d(s)}\to\bar{B}^0_{d(s)})}$$

and

$$P_{d(s)}=\text{prob}(b\to B^0_{d(s)})\frac{B(B^0_{d(s)}\to l^+X)}{B(b\to B\to l^\pm X)}\,,$$

requires a measurement of the fractions P_d and P_s [1]. By assuming the same branching ratio for semileptonic decays of all B mesons, assuming B_u, B_d, and B_s are produced in the ratio 0.375:0.375:0.15 [4], we obtain constraints on the χ_d-χ_s plane shown in Fig. 2. The ARGUS and CLEO combined results for χ_d and the standard-model predictions [12] are also shown. Our results are consistent with recent measurements of $B^0\bar{B}^0$ mixing by other experiments [4].

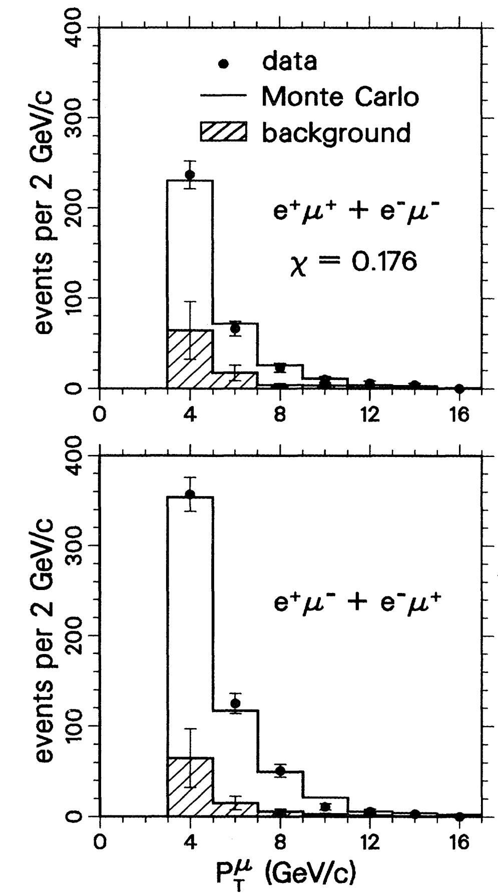

FIG. 1. Muon P_T spectra for the data, the Monte Carlo model with the observed mixing, and background in like-sign and opposite-sign $e\mu$ events. The uncertainties for the data are statistical only, while those for the background are 47% as described in the text. Both the data and the Monte Carlo model include the background.

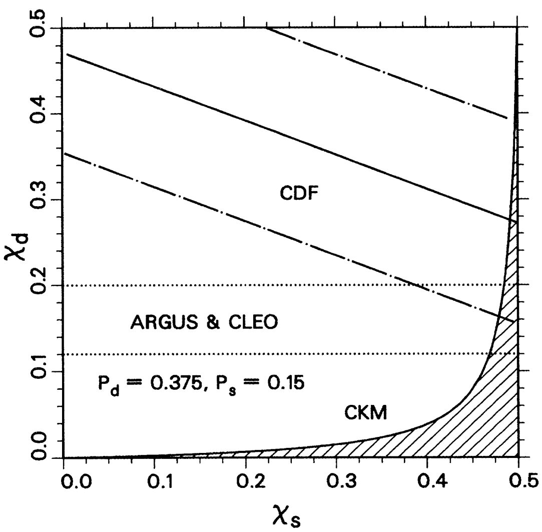

FIG. 2. The mixing probability of B_d^0 vs that of B_s^0, assuming B_u, B_d, and B_s are produced in the ratio 0.375:0.375:0.15. The χ_d range is the ARGUS and CLEO combined result of 0.16 ± 0.04. The shaded region is allowed by the standard model. The bands represent $\pm 1\sigma$ uncertainty.

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[(a)]Visitor.

[1] UA1 Collaboration, H. C. Albajar *et al.*, Phys. Lett. B **186**, 247 (1987).
[2] ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. B **192**, 245 (1987); CLEO Collaboration, M. Artuso *et al.*, Phys. Rev. Lett. **62**, 2233 (1989).
[3] MAC Collaboration, H. Band *et al.*, Phys. Lett. B **200**, 221 (1990); MARK II Collaboration, A. J. Weir *et al.*, Phys. Lett. B **240**, 289 (1990).
[4] L3 Collaboration, B. Adeva *et al.*, Phys. Lett. B **252**, 703 (1990); ALEPH Collaboration, D. Decamp *et al.*, Phys. Lett. B **258**, 236 (1991); UA1 Collaboration, H. C. Albajar *et al.*, Phys. Lett. B **262**, 171 (1991).
[5] F. Abe *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **271**, 387 (1988).
[6] F. Abe *et al.*, Phys. Rev. Lett. **64**, 147 (1990); L. Song, Ph.D. thesis, University of Pennsylvania, 1991 (unpublished).
[7] F. Abe *et al.*, Phys. Rev. **40**, 3791 (1989).
[8] F. Abe *et al.*, Phys. Rev. Lett. **61**, 1819 (1988).
[9] F. Abe *et al.*, Phys. Rev. Lett. **63**, 1447 (1989).
[10] F. Paige and S. D. Protopopescu, BNL Report No. BNL 38034, 1986 (unpublished). ISAJET version 6.22 was used for this analysis.
[11] Particle Data Group, J. J. Hernandez *et al.*, Phys. Lett. B **239**, 1 (1990). For the *b* semileptonic branching ratio, we have used the average of SLAC PEP and DESY PETRA results.
[12] C. S. Kim, J. L. Rosner, and C.-P. Yuan, Phys. Rev. **42**, 96 (1990), solution 1. For the formalism used, see P. J. Franzini, Phys. Rep. **173**, 1 (1989).