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Measurement of $B^0-\bar{B}^0$ Mixing Using Dimuons at D0

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MEASUREMENT OF $B^\circ - \bar{B}^\circ$ MIXING USING DIMUONS AT DØ

The DØ Collaboration[1]

(July 1995)

The DØ experiment at Fermilab has determined the $B^\circ - \bar{B}^\circ$ mixing probability χ using dimuon events produced in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. Using a sample of 172 dimuon events, we have determined the time and flavor averaged mixing probability χ to be $0.09 \pm 0.04(stat) \pm 0.03(sys)$ [preliminary] in agreement with the present world average.

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INTRODUCTION

Mixing between B° and its anti-particle can occur in the Standard Model via well-known box diagrams which result from the non-conservation of quark flavor in the weak interaction. The time averaged mixing probability χ is given in terms of the mixing parameter x as

$$\chi = \frac{P(B^\circ \to \bar{B}^\circ)}{P(B^\circ \to B^\circ) + P(B^\circ \to \bar{B}^\circ)} \approx \frac{x^2}{2+2x^2}, \tag{1}$$

where x is the mass difference of the mass eigenstates divided by their average decay width. The mixing parameters x_d and x_s are of interest because they can be written in terms of parameters of the Standard Model. In particular, x_d and x_s depend on the CKM matrix elements V_{td} and V_{ts}. An accurate measurement of χ (or χ_s) can be used to set a lower limit on x_s and thus help constrain elements of the CKM matrix.

In the case of the semileptonic decay of B hadrons into muons, the combined mixing probability χ is redefined as

$$\chi = \frac{BR(b \to B^0 \to \bar{B^0} \to \mu^+)}{BR(b \to \mu^\pm)}, \tag{2}$$

which is an average over both B_d° and B_s° mesons which can mix as well as charged B mesons and other B hadrons which cannot. The sign of the muon produced via the semileptonic decay of the B^0 or $\bar{B^0}$ can be used to tag events in which mixing has occurred.

Label	Primary Process	$++/--$	$+-$
P1	$b \to \mu^-, \bar{b} \to \mu^+$	$2\chi(1-\chi)$	$(1-\chi)^2+\chi^2$
P2	$b \to c \to \mu^+, \bar{b} \to \mu^+$	$(1-\chi)^2+\chi^2$	$2\chi(1-\chi)$
P3	$b \to c \to \mu^+, \bar{b} \to \bar{c} \to \mu^-$	$2\chi(1-\chi)$	$(1-\chi)^2+\chi^2$
P4	$c \to \mu^+, \bar{c} \to \mu^-$	0%	100%
P5	$\pi, K \to \mu$ background	50%	50%

TABLE 1. Sources of dimuon events.

Experimentally, one measures the ratio R of like to unlike sign dimuons. In order to extract χ from R it is necessary to model the relative contributions of all processes which contribute to dimuon production. Using the redefined mixing probability χ, the fraction of like and unlike sign dimuons in the presence of mixing is given in Table 1 for the different production processes. The Υ and Drell-Yan contributions to our dimuon sample described below are negligible and hence are not included as potential sources. Once the relative fractions of the contributing processes are modeled using Monte Carlo, χ can be extracted from R as the solution to a quadratic equation.

TRIGGER AND SELECTION CUTS

The DØ detector has been described in detail elsewhere (1). The data set used in this preliminary analysis was collected during the FNAL 1992-93 collider run using both a dimuon and a single muon plus jet trigger. The dimuon trigger required two good muon candidates in $|\eta| < 1.7$ with $p_T^\mu \geq 3$ GeV/c, while the muon plus jet trigger required one good muon candidate in $|\eta| < 1.7$ with $p_T^\mu \geq 3$ GeV/c and one reconstructed jet in $|\eta| < 3.5$ with $E_T^{jet} \geq 10$ GeV. The corresponding integrated luminosities for these triggering conditions in our data sample were 6.6 pb^{-1} and 3.7 pb^{-1} respectively. The offline cuts for the mixing analysis required two high quality muon tracks in the region $|\eta| < 0.8$. For each track energy deposition of at least 1 GeV was required in the calorimeter cells along the muon track plus their nearest neighbors. Matching central detector tracks were also required. The transverse momentum of each muon was constrained to the range $4 < p_T^\mu < 25$ GeV/c with the added requirement that $\int B\, d\ell > 0.5$ GeV along the muon track to help ensure a good momentum measurement.

Additional criteria were imposed to help remove specific backgrounds from the data sample. The dimuon opening angle was required to be less than 165° to help lower the cosmic ray background. The dimuon effective mass was required to be between 6 GeV and 40 GeV to remove events from J/ψ and Z^0 decay. In addition, each event was required to have at least one associated jet where an associated jet was defined as a jet with $E_T^{jet} > 12$ GeV within $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.8$ of the muon. Further, all muons having associated jets in the event were required to satisfy $p_T^{rel} > 1.2$ GeV/c where p_T^{rel} is the transverse momentum of the muon relative to the jet axis. Here the jet axis was determined using the vector addition of the muon and jet momenta. These cuts were applied to remove events from Drell-Yan and Υ production for which isolated muon candidates are expected as well as to enhance the fraction of dimuons coming directly from $b\bar{b}$ decay.

DATA ANALYSIS

Using these cuts we find a total of 59 like sign and 113 unlike sign dimuon events. The fraction of cosmic rays in these events is estimated by performing a maximum likelihood fit to the *floating* t_0 distributions for the muon tracks in the data sample. The *floating* t_0 parameter for a given muon track is determined via a refit of the track which leaves the beam crossing time as a free parameter in the fit. The best beam crossing time from this fit is the *floating* t_0, the distribution of which is peaked sharply at zero for beam produced events and flatter for randomly dispersed cosmic rays. The predicted remaining background of cosmic ray events from this fit is also cross checked against the results of a visual event scan for cosmics in the sample. Both methods are seen to agree within errors. Correcting for the estimated cosmic ray background, one finds the ratio of like to unlike sign dimuons to be

$$R = \frac{\text{like sign}}{\text{unlike sign}} = 0.43 \pm 0.07(stat) \pm 0.05(sys) \tag{3}$$

where the systematic error reflects the uncertainties associated with the fits used to estimate the background fraction of cosmic rays.

The relative contributions of the different dimuon production processes were determined using ISAJET Monte Carlo plus the full DØ detector and trigger simulations. The relative fractions of the contributing processes to the data sample are shown in Table 2. Sources of systematic error to the relative fractions given by the Monte Carlo were investigated using checks from the data wherever possible. The Monte Carlo prediction for the fraction of muon tracks reconstructed with the wrong sign was checked against the respective number of Υ candidates obtained from fits to the like and unlike sign isolated, high mass dimuon data samples. The fraction of Υ candidates from like sign dimuon pairs was found to be consistent with the Monte Carlo prediction for wrong sign track reconstruction, and the error range of the fits was used to establish an uncertainty range on the Monte Carlo prediction.

The Monte Carlo prediction for the relative fractions of muons coming from b, c, and π/K decay was checked using a data sample of single muons which had associated jets (2). A maximum likelihood fit to the transverse momentum of the muon track relative to the associated jet axis (p_T^{rel}) was utilized to extract the fraction of muons from b quark decays relative to the entire sample. The fraction of muons resulting from b quark decay predicted by ISAJET was consistent with that found by the p_T^{rel} fit method within the uncertainties of both methods. Since the p_T^{rel} spectra for muons from c quark and π/K decays are similar, separation of the relative contributions from these processes is difficult. Therefore, a large uncertainty of 50% is assigned to the Monte Carlo prediction for the magnitude of the $c\bar{c}$ and heavy flavor plus π or K decay processes.

Additional sources of systematic error on the relative fractions shown in Table 2 result from uncertainties in the semileptonic branching ratios for both b and c quarks, ambiguity in the fraction of events which contain multiple heavy quark pairs, and disagreement in jet trigger efficiency between data and Monte Carlo. The effect of each source of systematic error on the relative fractions of the different dimuon production processes is illustrated in Table 3.

Label	Primary Process	Fraction	Total Error
P1	$b \to \mu^-, \bar{b} \to \mu^+$	0.69	0.06
P2	$b \to c \to \mu^+, \bar{b} \to \mu^+$	0.16	0.03
P3	$b \to c \to \mu^+, \bar{b} \to \bar{c} \to \mu^-$	0.02	0.01
P4	$c \to \mu^+, \bar{c} \to \mu^-$	0.03	0.01
P5	$\pi,K \to \mu$ background	0.10	0.04

TABLE 2. Relative fractions of dimuon production processes as determined from Monte Carlo.

Error Type	P1	P2	P3	P4	P5
$BR(b \to \mu)$	0.012	0.004	0.002	0.003	0.004
$BR(c \to \mu)$	0.020	0.010	0.003	0.004	0.003
Incorrect Sign ID	0.011	0.011	0.000	0.000	0.000
Multiple $b\bar{b}$,$c\bar{c}$ Pairs	0.018	0.002	0.001	0.001	0.017
f_b	0.004	0.001	0.000	0.005	0.000
f_c	0.023	0.005	0.001	0.009	0.020
f_{decay}	0.014	0.003	0.001	0.001	0.018
MC Jet Trigger	0.003	0.002	0.000	0.002	0.003
MC Statistics	0.040	0.020	0.007	0.008	0.014
Total Error	0.058	0.026	0.008	0.014	0.035

TABLE 3. Effect of each source of systematic error on the relative fractions determined for the different dimuon production processes.

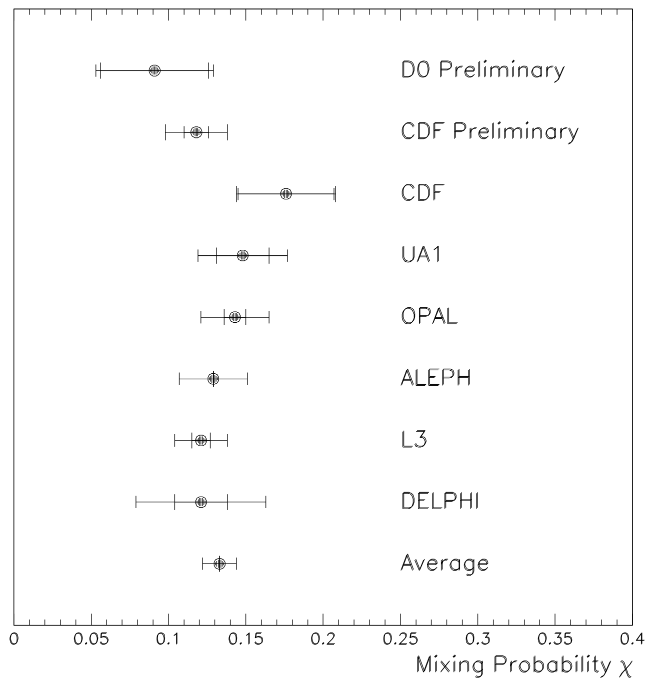

FIG. 1. Mixing probability measurements. The average does not include preliminary DØ and CDF results.

RESULTS AND CONCLUSIONS

Combining the experimental parameter R, as given in equation (3), with the relative fractions of the dimuon production processes as presented in Table 2 we determine the time and flavor averaged mixing parameter χ to be

$$\chi = 0.09 \pm 0.04(stat) \pm 0.03(sys) \qquad (Preliminary). \qquad (4)$$

The measured value for χ is in agreement with other recent experimental results from UA1 (3), CDF (4) (5), and LEP (6) (7) (8) (9) as shown in Fig. 1.

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