Fermi National Accelerator Laboratory

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DØ

Study of B^0-$\bar{B}^0$ Mixing in DØ

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Disclaimer

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The probability of B^0-$\overline{B}^0$ mixing has been measured using the DØ detector. Non-isolated dimuon events are used to determine the ratio of like to unlike-sign pairs. The measured ratio is $0.48 \pm 0.04(stat.) \pm 0.03(syst.)$, compared with the expected value of 0.23 ± 0.07 in the absence of B^0-$\overline{B}^0$mixing. The combined mixing probability is measured to be $0.13 \pm 0.02(stat.) \pm 0.05(syst.)$ in good agreement with other experimental measurements.

1. Introduction

Mixing in the B^0-$\overline{B}^0$ system arises in the standard model dominantly from box diagrams involving virtual top quarks. The probability of mixing depends on the decay constant of the B meson, the mass of the top quark and the Cabibbo-Kobayashi-Maskawa matrix elements of V_{td} and V_{ts}. The measured probability for the mixing of the B_d system by the ARGUS and CLEO experiments [1] and the relation between V_{td} and V_{ts} from unitarity constraints of the CKM matrix [2] suggest that the mixing of the B_s system is full. CDF, UA1, and LEP measurements [3] are also consistent with full mixing of B_s. More accurate measurements of the mixing probability can be used to make further constraints on the CKM matrix elements.

We have measured the combined B^0-$\overline{B}^0$ mixing using dimuon events. The mixing probability χ is defined as

$$\chi = \frac{prob(b \to B^0 \to \overline{B}^0 \to \mu^+ X)}{prob(b \to \mu^\pm X)} ,$$

where the denominator includes all b-flavored hadrons produced. At the Tevatron, both $B_d^0(\bar{b}d)$ and $B_s^0(\bar{b}s)$ are produced as well as charged B mesons and b-flavored baryons. The measured probability χ is related to the mixing probabilities of the B_d^0 and B_s^0 systems as

$$\chi = f_d\chi_d + f_s\chi_s ,$$

where f_d and f_s are the fractions of B_d^0 and B_s^0 mesons produced relative to all b-flavored hadrons, and χ_d and χ_s are the mixing parameters of B_d^0 and B_s^0 mesons, respectively.

The sign of the muon from the semileptonic decay is used to tag the flavor of the b quark. Experimentally, one measures the ratio of like-sign dimuon events to unlike-sign dimuon events,

$$R = \frac{N(\mu^+\mu^+) + N(\mu^-\mu^-)}{N(\mu^+\mu^-)} .$$

Primary decays of $b\bar{b}$ events produce unlike-sign dimuon pairs if neither of the b hadrons has mixed, while like-sign dimuon pairs are produced if one of the b hadrons has mixed. There are background processes, in which one of the muons is from a secondary decay, $b \to c \to \mu$, or π/K decay, which can produce like and unlike-sign dimuon events. Monte Carlo simulations have been used to estimate the fraction of all processes that produce dimuon events. The contribution of processes is given in Table 1. Once the ratio R and the relative fractions of the contributing processes are known, the mixing probability will be a solution to a quadratic equation. The offline event selection criteria should be optimized to maximize the process of dimuon events in which both muons come from primary b decays. Uncertainties in the measurement of the mixing probability will then be minimized.

Process	Type	Like-Sign	Unlike-Sign
P1	$b \to \mu^-, \bar{b} \to \mu^+$	$2\chi(1-\chi)$	$(1-\chi)^2 + \chi^2$
P2	$b \to \mu^-, \bar{b} \to \bar{c} \to \mu^-$	$(1-\chi)^2 + \chi^2$	$2\chi(1-\chi)$
P3	$b \to c \to \mu^+, \bar{b} \to \bar{c} \to \mu^-$	$2\chi(1-\chi)$	$(1-\chi)^2 + \chi^2$
P4	$b \to c\mu^-, c \to \mu^+$	0%	100%
P5	$c \to \mu^+, \bar{c} \to \mu^-$	0%	100%
P6	Drell-Yan, J/ψ, Υ	0%	100%
P7	decay background	50%	50%

Table 1: Fraction of like and unlike-sign dimuons from contributing processes

2. Data analysis

DØ and its muon detector have been described in detail elsewhere [4]. This analysis is based on a data sample collected between December 1992 and May 1993 and corresponds to an integrated luminosity of 10.5 pb^{-1}.

The trigger requirements included:

- two muons in the $|\eta| < 1.7$ region (hardware trigger) and
- two muons with $p_T > 3GeV/c$ and $|\eta| < 1.7$ (software trigger).

Two and three muon events are selected in the offline based on the following selection criteria.

- good track fit and good vertex projection
- $|\eta| < 1.1$

- Calorimeter energy deposition along the muon track $> 1\ GeV$
- $\Delta\phi_{\mu\mu} < 160°$ (cut on the dimuon azimuthal opening angle to reject cosmic rays)
- $m_{\mu\mu} > 6\ GeV/c^2$ (removes J/ψ's)
- $2 < p_T^\mu < 25\ GeV/c$ (ensures proper sign determination)

Jets were then found using a fixed cone algorithm with a radius $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ of 0.7. At least one muon must be associated with a jet within a cone of 0.8 in ΔR.

To enhance the signal of muons from primary b decays, further selection is done using a cut of $p_T^{rel} > 1.2\ GeV/c$ for all muons with an associated jet, where p_T^{rel} is transverse momentum with respect to jet axis. The variable p_T^{rel} depends on the mass of the initial quark and the decay chain. Because the b quark is heavier than the c quark, muons from the primary b decay tend to have larger values of p_T^{rel}. The cut value of 1.2 GeV/c is chosen to maximize the signal of muons from primary b decay while minimizing the background of muons from secondary b decay, c decay, and π/K decay. The effect of the cut on p_T^{rel} appears in the dimuon invariant mass distributions of Figure 1. Semileptonic b decay $b \to c\mu\nu$ and sequential semileptonic c decay $c \to s\mu\nu$ make dimuons with low mass and unlike-sign pairs. These dimuons are seen in the low mass region under the Gaussian distribution of $J/\psi \to \mu\mu$ in Figure 1a. Those dimuons are suppressed after the p_T^{rel} cut as shown in Figure 1c.

To determine the ratio of like-sign pairs to unlike-sign pairs, entries are counted in the region of $m_{\mu\mu} > 6\ GeV/c^2$ of Figure 1c and 1d for unlike-sign pairs and like-sign pairs respectively. We observed 218 like-sign pairs and 475 unlike-sign pairs. The background of cosmic ray events is estimated to be 20% from a visual scan of a subset of the sample. The ratio of like-sign pairs and unlike-sign pairs of cosmic ray events are estimated and subtracted from the dimuon sample. The ratio is obtained to be $0.48 \pm 0.04(stat.) \pm 0.03(syst.)$, where the systematic error comes from uncertainties of the cosmic ray background subtraction. In the absence of B^0-$\overline{B}^0$ mixing, Monte Carlo simulations predict 0.23 ± 0.07. This is inconsistent with the observed value of the ratio R and implies that B^0-$\overline{B}^0$ mixing is strong.

3. Monte Carlo simulation

The ISAJET V.6.48 Monte Carlo program was used to generate 35000 dimuon events from $b\bar{b}$ and $c\bar{c}$ processes including higher order production mechanisms. Events are then processed through the fast DØ detector simulator which employes the parameterization of the DØ detector response to hadrons and leptons as well as the hardware and software trigger efficiencies. The accuracy of the fast simulator was tested with a smaller sample of ISAJET events with the full DØ GEANT simulator. QCD events are generated with ISAJET for estimating the background of muons from π/K decay. A smaller sample, corresponding to an integrated luminosity of 0.02 nb^{-1}, was generated while probabilities of π/K decay were enhanced by a factor of 100.

The relative contributions of all dimuon production processes is listed in Table 2. Note the process P1, in which both muons from primary b decays, has the largest fraction of contributing processes.

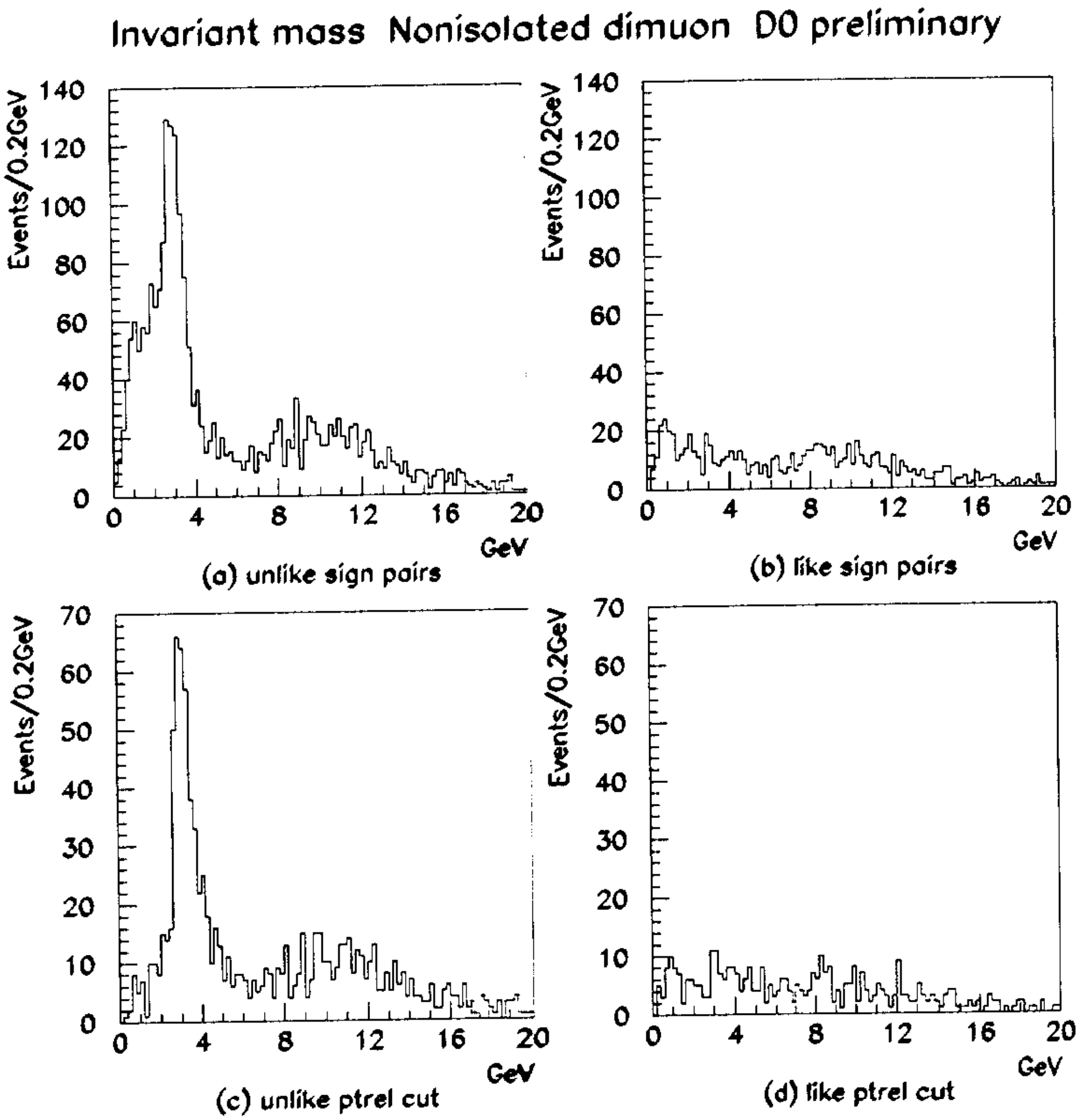

Figure 1: Invariant mass distributions of nonisolated dimuon pairs of the sample before the p_T^{rel} cut (unlike-sign pairs (a), like-sign pairs (b)), and the sample after the p_T^{rel} cut (unlike-sign pairs (c), like-sign pairs (d)).

Process	Type	Fraction
P1	$b \to \mu^-, \bar{b} \to \mu^+$	0.75 ± 0.10
P2	$b \to \mu^-, \bar{b} \to \bar{c} \to \mu^-$	0.16 ± 0.05
P3	$b \to c \to \mu^+, \bar{b} \to \bar{c} \to \mu^-$	0.01 ± 0.01
P4-P6	$b \to c\mu^- + c \to \mu^+$, $c\bar{c}$, J/ψ, Υ	0.03 ± 0.03
P7	decay background	0.06 ± 0.02

Table 2: Fraction of contributing processes to dimuon events

Process	Monte Carlo statistics	Cross section	Fragment-ation	Branching ratio	Detector simulation	Total error
P1	0.06		0.02	0.07	0.04	0.10
P2	0.03		0.02	0.02	0.03	0.05
P3	0.01					0.01
P4-P6	0.01	0.03				0.03
P7	0.02				0.01	0.02

Table 3: Contributions of systematic uncertainties

Several sources of systematic uncertainties, as well as Monte Carlo statistics, contribute to the errors in the estimated fractions. The uncertainty in the ratio of $c\bar{c}$ and $b\bar{b}$ cross section is assigned to be 100%. For fragmentation, the parameter ϵ_B of the Peterson function in ISAJET was changed with an uncertainty of 37% suggested from PEP and PETRA experiments. A systematic uncertainty of 10% was considered for the branching ratio of the semileptonic decay of $B \to \mu + X$ and 15% for the secondary b decay of $D \to \mu + X$. For the parameterization of detector simulation, we considered the uncertainty of the muon trigger efficiency curve. The contribution of each kind of uncertainty to the errors in the estimated fractions is listed in Table 3.

Our estimation of the fraction of contributing processes has been checked using the p_T^{rel} distribution. Figure 2 shows that the data distribution is in agreement with the prediction of Monte Carlo simulations, indicating that our Monte Carlo model correctly simulates all processes that produce dimuon events.

4. Preliminary results and conclusions

Together with the measurement value of the ratio of like to unlike-sign dimuon pairs, the estimated values of the fractions are used to complete the quadratic equation,

$$2\chi - 2\chi^2 = \frac{R(P1 + P3 + P4 + P5 + P6 + 0.5P7) - P2 - 0.5P7}{(1 + R)(P1 - P2 + P3)}$$

and to determine the mixing probability χ. Our preliminary value for the B^0-$\overline{B}^0$ mixing parameter is

$$\chi = 0.13 \pm 0.02\,(stat.) \pm 0.05\,(syst.)\,.$$

This is in good agreement with published results from CDF, UA1, and LEP experiments. It should be noted that statistical error is small. The systematic error can be reduced with optimization of the event selection, applying other techniques in estimating the fraction of contributing processes, and increased Monte Carlo statistics.

Our preliminary result of the combined mixing probability can be translated into a limit in the $\chi_d - \chi_s$ plane. Assuming the same branching ratio for semileptonic decays of all B mesons and assuming B_u, B_d and B_s are produced in the ratio of 0.375 : 0.375 : 0.15, our limit is shown in Figure 3. The ARGUS and CLEO results for χ_d and the standard model predictions are also shown.

While muons with $|\eta| < 1.1$ only are used in this analysis, we are now extending our analysis to the larger coverage. Further we expect an order of magnitude more dimuon events with increased Tevatron luminosity and trigger upgrades for the coming run 1b. With reduced statistical and systematic errors, we should be able to make further constraints in the $\chi_d - \chi_s$ plane.

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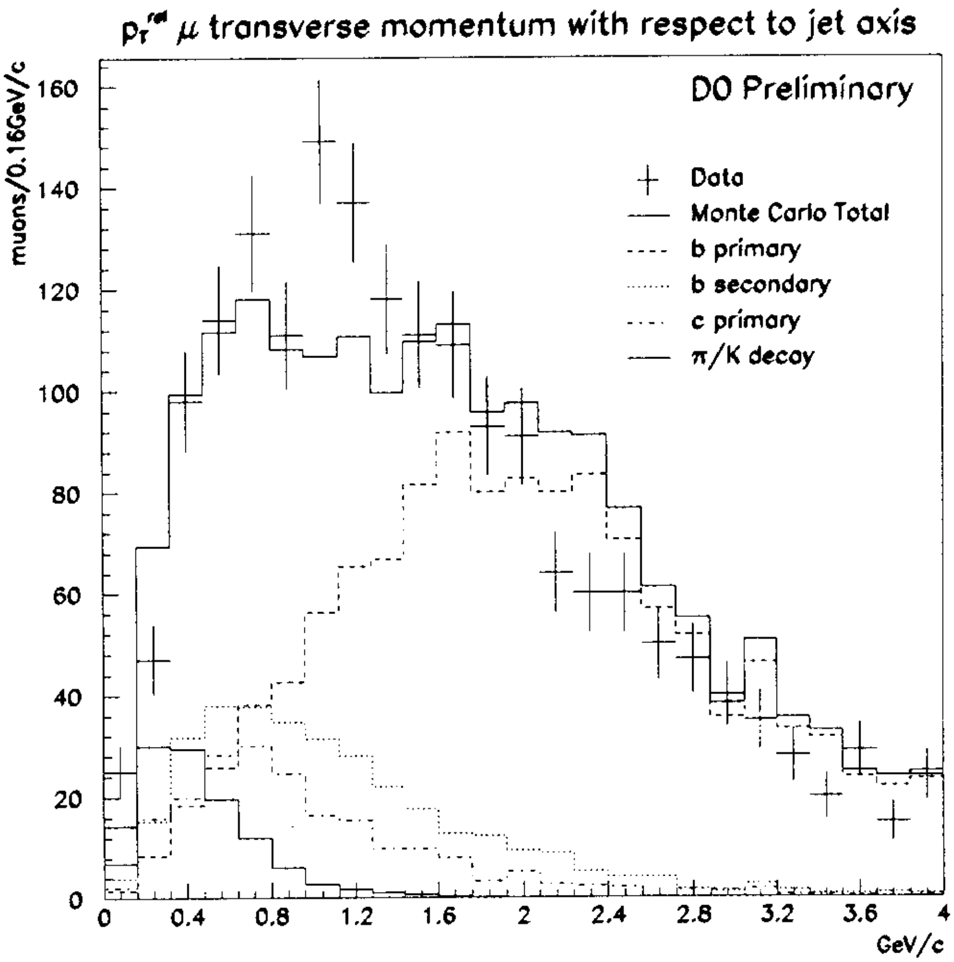

Figure 2: Distributions of p_T^{rel} of the data. The solid histogram is Monte Carlo prediction. Monte Carlo distributions for muons of individual sources are also shown.

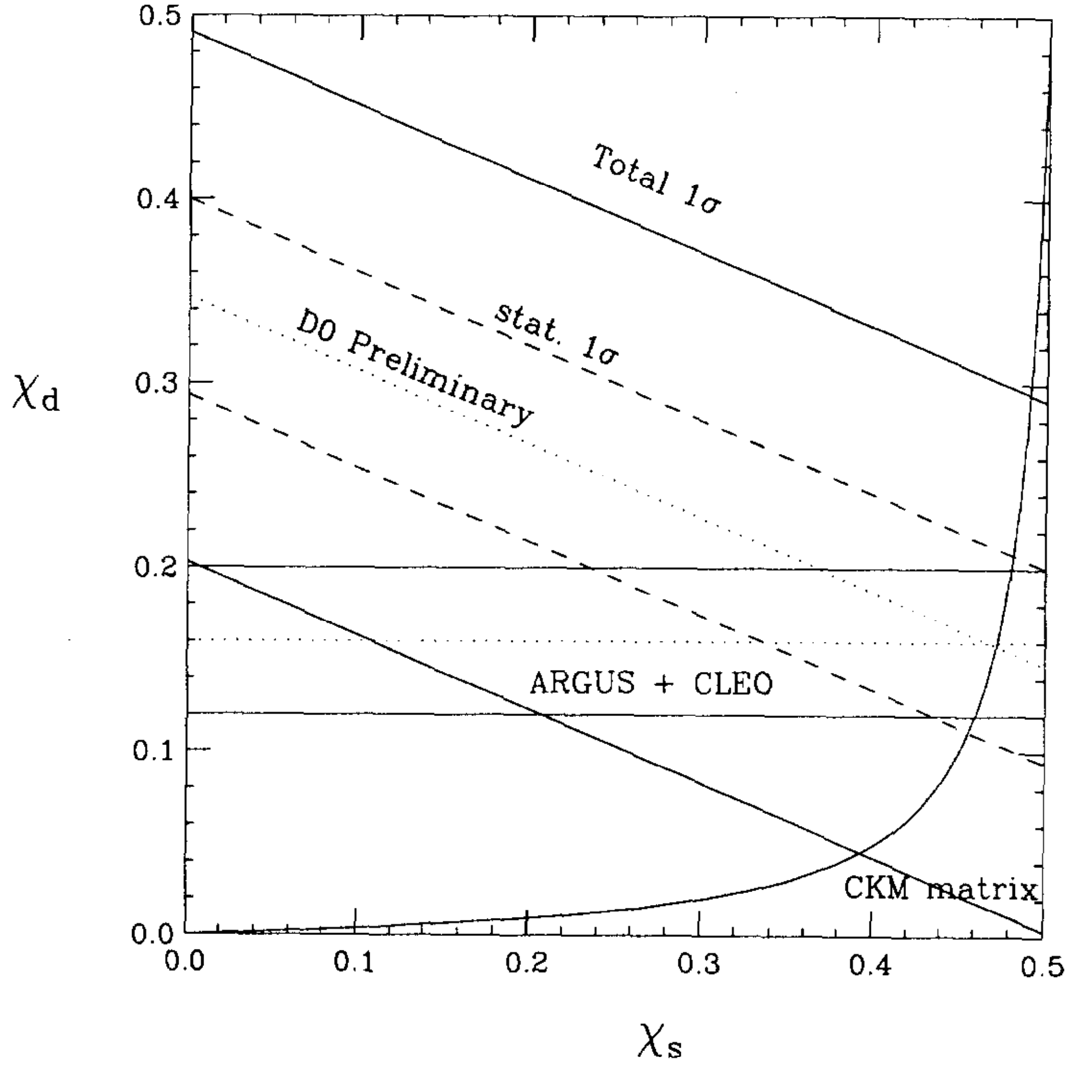

Figure 3: The DØ limit in the plane of $\chi_d - \chi_s$ assuming B_u, B_d and B_s are produced in the ratio of 0.375 : 0.375 : 0.15. The range of χ_d is from the ARGUS and CLEO experiments. Below the curve is the region allowed by the standard model.