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MEASUREMENT OF $B^0-\overline{B}^0$ MIXING USING THE MARK II AT PEP*

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Frank PORTER
Representing the MARK II Collaboration[1]

California Institute of Technology, Pasadena, CA 91125, USA
and Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309, USA

1. INTRODUCTION

$B^0\overline{B}^0$ mixing has been observed now by several experiments.[2] The signature is the observation of an excess of same-sign dilepton events in datasets containing semileptonic B decays. Several years ago the MARK II published an upper limit on $B^0\overline{B}^0$ mixing at E_{cm} = 29 GeV, using data taken at the e^+e^- storage ring PEP.[3] Here we report on the results of a new analysis with increased statistics, using refined methods with better sensitivity and control of systematic effects.[4]

2. ANALYSIS

The data were taken by the MARK II detector in two configurations at PEP. The detectors are described in detail elsewhere.[5] The dataset for this analysis corresponds to an integrated luminosity of 224 nb^{-1}, of which 15 nb^{-1} is from the upgrade version of the detector.

Hadronic event selection is made using the following cuts:

1. The charged multiplicity is at least 5, where a charged track must pass within 4 cm of the beam line and within 6 cm of $z = 0$ at the point of closest approach to the beam line.
2. The sum of the magnitudes of the charged track momenta in the event must be greater than 3 GeV.
3. The total charged and neutral visible energy must be greater than 7.5 GeV.
4. The thrust axis of the event must be well away from the beam direction: $|\cos\theta_{thrust}| < 0.7$.
5. There must be at least one cluster (jet) in the event, excluding the lepton candidate(s). Clusters are found using our standard cluster-finding procedure,[6] using only the charged tracks, and a value $y_{cut} = 0.05$.

A total of 81,744 events passed these cuts.

Lepton identification using the MARK II detector has been discussed in detail in a previous publication.[7] In this analysis, electrons are required to have momenta greater than 1 GeV/c, and muons are required to have momenta greater than 1.8 GeV/c. Muons are identified using a relatively loose, three standard deviation road about the direction of the track, extrapolated from the drift chamber.

We define the transverse momentum (p_T) of a track to be the component of the track's momentum perpendicular to the closest charged-particle cluster in the event. This definition avoids possible transverse momentum correlations between the two leptons in a dilepton event, which would be present if the transverse momentum were calculated with respect to the event thrust axis.

Before considering lepton charges, an analysis of both the events containing a single identified lepton and the events containing two leptons (separated by at least

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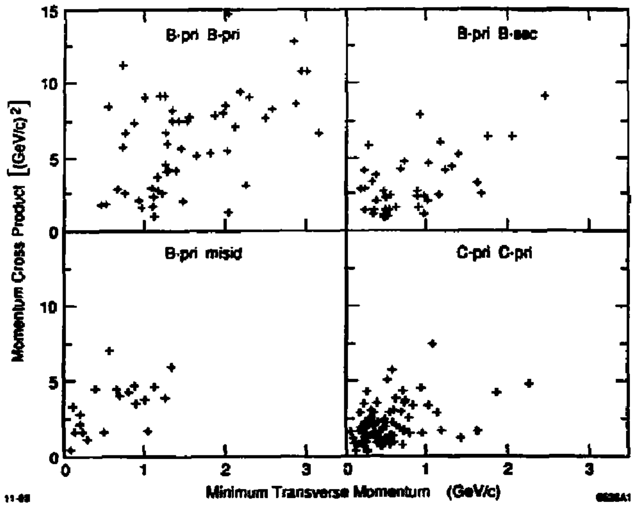

FIGURE 1
Four simulated dilepton distributions normalized to the size of the hadronic data sample.

90 degrees) is performed in order to extract the contributions from various sources:

1. Backgrounds from hadron misidentification.
2. Decays of $\pi^\pm, K^\pm \rightarrow \mu^\pm$; photon conversions; Dalitz decays.
3. Primary b-quark decay.
4. Primary c-quark decay.
5. Secondary b-decay (decay of c-quark in $b\bar{b}$ events).

A simultaneous fit is performed to the (a) one-electron, (b) one-muon, (c) two-electron, (d) two-muon, and (e) electron-muon samples to distributions from Monte Carlo simulations [LUND 6.3 (Ref. 8) with the second-order QCD matrix element and the Peterson fragmentation function[9]] in the following variables:

1. For the one-lepton samples, the distributions in momentum (p) and p_T are fit.
2. For the two-lepton samples, the kinematic variables are $p_{T\min} \equiv \min(p_{T1}, p_{T2})$ and $|\vec{p}_1 \times \vec{p}_2|$. The indices 1 and 2 refer to the two leptons. Note that the cross product variable is large for high-momentum lepton pairs which are relatively acollinear, as expected to occur often in $b\bar{b}$ events where both b-quarks decay semileptonically.

Included in the simulations are leptons from the above sources. The background lepton distributions are obtained from parametrizations of the per-track misidentification and decay probabilities.[7] The eight variables in the fit are the average semileptonic branching ratios for b- and c-hadron decays to electrons and muons, and multiplicative scale factors for the electron and muon misidentification and decay backgrounds.

In order to avoid backgrounds from two-photon processes and tau pairs, events which contain one or more leptons with $p > 7.5$ GeV/c and $p_T > 3.5$ GeV/c are

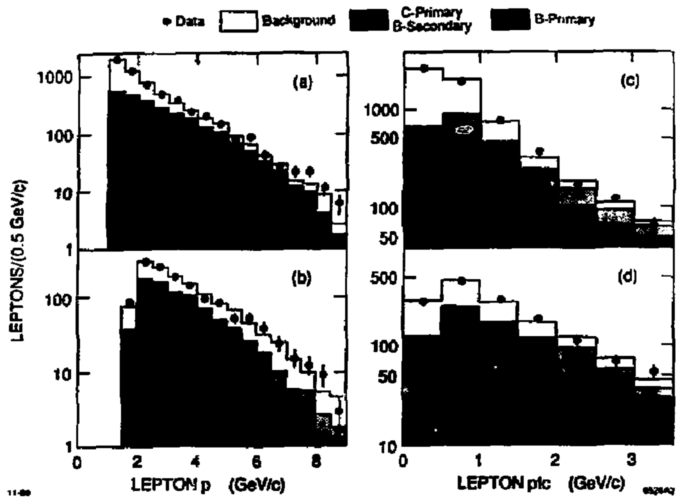

FIGURE 2

Single lepton momentum and transverse momentum ($p_{tc} = p_T$) distributions, with fitted contributions from various sources shown. (a) and (c) are the electron sample; (b) and (d) are the muon sample. Note the logarithmic scale.

rejected. Also, in the one-lepton sample the lepton is required to have a charged-particle cluster found within 90 degrees. Background electrons from Dalitz π^0 decays and photon conversions are removed by a pair-finding algorithm.[10] After all cuts, there remain 6108 candidate electrons, and 1568 candidate muons in the single-lepton sample, and 191 electron-electron, 117 electron-muon, and 23 muon-muon pairs in the two-lepton sample. We estimate that less than 1.4% of the one-lepton events, and less than 1.2% of the two-lepton events come from tau-pair and two-photon backgrounds.

We show the simulated $|\vec{p}_1 \times \vec{p}_2|$ *vs.* $p_{T\min}$ distributions for four dilepton combinations in Fig. 1. These distributions contain the expected numbers of events present in the hadronic data sample. For large values of the momentum cross product and $p_{T\min}$ the b-primary–b-primary dileptons are essentially background-free.

TABLE 1

Results of the one- and two-lepton fit. The errors are the statistical and systematic errors, respectively.

Parameter	Result (%)
$Br(B \to e)$	$13.7 \pm 0.8 \pm 1.3$
$Br(B \to \mu)$	$13.7 \pm 1.1 \pm 1.1$
$Br(C \to e)$	$11.0 \pm 0.8 \pm 1.7$
$Br(C \to \mu)$	$7.9 \pm 1.1 \pm 1.1$

The results of the fit, shown in Table 1, agree well with our previously published values for the b- and c-hadron semileptonic branching ratios. The observed and predicted distributions for the one-lepton samples are shown in Fig. 2.

The background scaling factors found in the fit were: $1.03 \pm 0.05 \pm 0.40$ for the electron backgrounds; and $0.86 \pm 0.04 \pm 0.35$ for the muon backgrounds, in good agreement with the value of one expected from the *a priori* background estimates.

To look for B-mixing, we define the probability, χ, that a hadron (at PEP), containing a b ($\bar{b}$) quark, decays to a positive (negative) lepton. The value of χ is extracted from the dilepton data by a likelihood fit to the like and unlike sign distributions in $p_{T\min}$ and $|\vec{p}_1 \times \vec{p}_2|$. The assumptions that go into this analysis are as follows:

1. CP-violation is neglected.
2. Dileptons containing backgrounds from misidentified hadrons or light quark decays are assumed to have equal like- and unlike-sign probability, except for a slight correlation between quark charge and lepton charge measured using single lepton data and incorporated into the likelihood (unlike sign/like sign $= 1.066 \pm 0.028$).
3. All c-primary-c-primary dileptons are assumed to have opposite charge (*i.e.*, no D-mixing).
4. The fraction of like-sign b-primary-b-primary dileptons is $2\chi(1-\chi)$.
5. The fraction of like-sign b-secondary-b-secondary dileptons is $2\chi(1-\chi)$.
6. The fraction of like-sign b-primary-b-secondary dileptons is $1 - 2\chi(1-\chi)$.
7. We have assumed in items 4, 5, and 6 that the b-hadron types in an event are uncorrelated.

The dilepton data (including now the charge information) are fit to the likelihood function:

$$\log \mathcal{L} = \sum_{ee,\mu\mu,e\mu} \left\{ \sum_{p_{T\min},|\vec{p}_1\times\vec{p}_2|}^{\text{same sign}} \log \frac{x_i^{n_i} e^{-x_i}}{n_i!} + \sum_{p_{T\min},|\vec{p}_1\times\vec{p}_2|}^{\text{opposite sign}} \log \frac{x_i^{n_i} e^{-x_i}}{n_i!} \right\} ,$$

where n_i is the observed number of events in bin i of the $p_{T\min}$, $|\vec{p}_1 \times \vec{p}_2|$ distribution, and $x_i = x_i(\chi)$ is the predicted number of events in bin i according to the value of the fit parameter χ.

3. RESULTS

The result of the likelihood fit is

$$\chi = 0.17^{+0.15}_{-0.08} ,$$

with 90% confidence level upper and lower limits of 0.38 and 0.06, respectively.

The errors include the estimated systematic uncertainties due to:

a. The b-fragmentation function used.

b. The uncertainty in the modelling of the leptonic backgrounds.

c. The uncertainty in the b- and c-hadron leptonic branching ratios (this source of error is negligible).

d. The possibility of tracking or other detector bias in the charge measurement (estimated to contribute < 0.4 like-sign events in the region sensitive to mixing).

e. There is a small probability for a b-quark jet to contain more than one charm hadron. The leptons produced by semileptonic decays of these charm hadrons will not necessarily be charge-correlated with the original b-quark charge. Using the Monte Carlo we estimate that $(14 \pm 5)\%$ of all B-secondary decays have the opposite charge to that expected. This effect is included in the calculation of the likelihood functions.

This result is most directly comparable to the MAC result,[2] also at 29 GeV, $\chi = 0.21^{+0.29}_{-0.15}$, which is consistent. Comparisons with the other experimental results are complicated by the differences in fractions of produced b-hadrons which are B_d and B_s. The Argus and Cleo results[2] are measured below B_s threshold, hence they measure the mixing for B_d alone: $\chi_d = 0.17 \pm 0.05$. Given that result, we predict, in Table II, the expected

TABLE II

Predictions for mixing at $E_{cm} = 29$ GeV.

B_d Fraction	B_s Fraction	χ: Full B_s Mixing	χ: No B_s Mixing
0.30	0.10	0.10 ± 0.02	0.05 ± 0.02
0.35	0.12	0.12 ± 0.02	0.06 ± 0.02
0.40	0.16	0.15 ± 0.02	0.07 ± 0.02
0.30	0.15	0.13 ± 0.02	0.05 ± 0.02
0.35	0.175	0.15 ± 0.02	0.06 ± 0.02
0.40	0.20	0.17 ± 0.02	0.07 ± 0.02

result for the MARK II under various assumptions for the B_d and B_s fractions in the extreme cases of full B_s mixing ($\chi_s = 0.5$) and of no B_s mixing ($\chi_s = 0$). Our result favors maximal B_s^0 mixing, with zero B_s^0 mixing disfavored at nearly the 90% confidence level.

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