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DILEPTONS, ELECTROWEAK CHARGE ASYMMETRY AND B - $\overline{B}$ MIXINGS*

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ABSTRACT

We discuss the implications of B - $\overline{B}$ mixings in e^+e^- annihilation and $\overline{p}p$ collisions. A comparative analysis of the recent data for the processes $e^+e^- \to \mu^\pm\mu^\pm X$ and $\overline{p}p \to \mu^\pm\mu^\pm X$ is presented in the context of standard model. An analysis of B - $\overline{B}$ mixing effects on the electroweak charge asymmetry in $e^+e^- \to b\overline{b} \to \ell^\pm X$ is also presented.

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Introduction

The standard model of electroweak interactions with three families of leptons and quarks seems to be in remarkable agreement with the presently available data. Despite this agreement the standard model has not yet been tested completely even at the born level. In particular, the charged weak currents, which are governed by a unitary 3x3 matrix, are not all well known. This circumstance can be traced back to the fact that presently only two of the four parameters of the Cabibbo-Kobayashi-Maskawa (CKM) matrix[1)] are well determined. Goldhaber has reported on the very impressive results on bottom meson life-time measurements, τ_B, at this conference: $\tau_B = (1.10 \pm 0.16) \times 10^{-12}$ sec. The measurements of τ_B, coupled with the lower bound[3)] $\overline{R} \equiv \Gamma(b \to u\ell\nu_\ell)/\Gamma(b \to c\ell\nu_\ell) \leq 0.04$ from CESR and DORIS experiments, have considerably constrained the CKM matrix elements. In the convenient parametrization of Wolfenstein[4)] one can express the CKM matrix as follows:

$$V \equiv \begin{pmatrix} Vud & Vus & Vub \\ Vus & Ves & Vcb \\ Vtd & Vts & Vtb \end{pmatrix} = \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^3)$$

The present experimental information then leads to the values:

$$\lambda \equiv \sin\theta_c \approx 0.23$$

$$A = 1.0 \pm 0.2$$

$$\rho^2 + \eta^2 < 0.3$$

Thus, the matrix elements V_{ub} and V_{td} are not yet determined and we note that both of these matrix elements as well as the CP-violation effects are of order λ^3 in the CKM model. Thus, much more stringent tests of the standard model will follow once the CKM-suppressed transitions V_{ub} and V_{td} become experimentally measurable. Of course, the interesting question is whether the CKM model provides a consistent explanation of the CP-violation effects. There are several ongoing experiments[5)] on the measurement of the CP-violating ϵ'/ϵ ratio in the kaon sector, which would put the standard model to a very stringent test. The present experimental situation is tantalizing but not yet conclusive[6)].

Another test of the standard model consists of measuring the strength of the $|\Delta B| = 2$ transitions. This involves B-$\overline{B}$ mixings among the neutral bottom mesons and their charge conjugates7). The $|\Delta B| = 2$ transitions, which are necessarily of higher order in the electroweak coupling constant, have a number of interesting phenomenological consequences, two of which have so far received experimental attention. The first concerns the production of same-sign dileptons in the processes $e^+e^- \to b\bar{b} \to \ell^\pm\ell^\pm X$ and $\bar{p}p \to b\bar{b} \to \ell^\pm\ell^\pm X$ 8). New results have been reported from the MARK-II Collaboration at PEP by Goldhaber2) and from the UA1 Collaboration at CERN by Watkins9) at this conference concerning dileptons in the final state. The second method involves the measurement of electroweak charge asymmetry in the process $e^+e^- \to b\bar{b} \to \ell^\pm X$, where the $|\Delta B| = 2$ interactions tend to decrease the electroweak asymmetry. This approach, pioneered by the JADE Collaboration at DESY10), involves one semi-leptonic branching ratio $b \to c\ell\nu_\ell$ instead of the product of two such ratios in the dilepton final state, and hence is quite promising from the statistical point of view. In this talk I will address both of these measurements and present an analysis based on the standard model.

B - $\bar{B}$ Oscillations: Theory

It is well known that the neutral weak currents in the standard model are manifestly diagonal and hence one needs the exchange of $W_L^+ W_L^-$ bosons to generate $|\Delta F| = 2$, $\Delta Q = 0$ transitions, like for example the B - $\bar{B}$ oscillations. The resulting box diagrams lead to the following mass differences11) ($\Delta M(B_d^0) \equiv \Delta M(B_d^1 - B_d^2)$, $\Delta M(B_s^0) \equiv \Delta M(B_s^1 - B_s^2)$ where B_q^i ($i = 1, 2$, $q = d, s$) are bottom meson states with definite life-times and masses):

$$\Delta M(B_d^0) = \frac{G_F^2 \, f_{Bd}^2 \, m_{Bd} \, \hat{B}}{6\pi^2} \, F_d(m_b, m_t, \lambda)$$

$$\Delta M(B_s^0) = \frac{G_F^2 \, f_{Bs}^2 \, m_{Bs} \, \hat{B}}{6\pi^2} \, F_s(m_b, m_t, \lambda) \qquad (1)$$

where $\hat{B}$ is the so-called bag constant, which enters through the definition

$$\langle B_d^0 | (\bar{b}\gamma_\mu (1-\gamma_5) d)^2 | \bar{B}_d^0 \rangle \equiv \frac{4}{3} \, \hat{B} \, f_{Bd}^2 \, m_{Bd}$$

$$\langle B_s^0 | (\bar{b}\gamma_\mu (1-\gamma_5) s)^2 | \bar{B}_s^0 \rangle \equiv \frac{4}{3} \, \hat{B} \, f_{Bs}^2 \, m_{Bs} \qquad (2)$$

and assumes the value $\hat{B} = 1$ in the vacuum insertion approximation; f_{Bd} and f_{Bs} are the bottom meson pseudoscalar coupling constants, analogous to f_π and f_K, and the functions F_d and F_s are given by

$$F_d(m_b, m_t,) = (\lambda_c^d)^2 \, u_1 + (\lambda_t^d)^2 \, u_2 + 2(\lambda_t^d)(\lambda_c^d) \, u_3$$

$$F_s(m_b, m_t,) = (\lambda_c^s)^2 \, u_1 + (\lambda_t^s)^2 \, u_2 + 2(\lambda_t^s)(\lambda_c^s) \, u_3 \qquad (3)$$

The CKM-angle dependent factors λ_i^j assume the following values in the Wolfenstein parametrization:

$$|\lambda_c^d| \equiv |V_{cb}^* \, V_{cd}| \sim \lambda^3$$

$$|\lambda_t^d| \equiv |V_{tb}^* \, V_{td}| \leq \frac{1}{2} \lambda^3$$

$$|\lambda_c^s| \equiv |V_{cb}^* \, V_{cs}| \sim \lambda^2 \qquad (4)$$

$$|\lambda_t^s| \equiv |V_{tb}^* \, V_{ts}| \sim \lambda^2$$

and the quark mass dependent factors u_i are given by (ignoring QCD corrections)

$$u_1 \sim m_c^2/m_W^2$$

$$u_2 \sim m_t^2/m_W^2 \qquad (5)$$

$$u_3 \sim m_t m_c/m_W^2$$

Thus, the dominant contribution in both $M(B_d^0)$ and $M(B_s^0)$ is due to the u_2 term. Since in the free-quark decay model one expects $\Gamma(B_d^0) \simeq \Gamma(B_s^0) \propto |V_{bc}|^2 \sim \lambda^4$, the phenomenologically interesting quantity for B-$\bar{B}$ oscillations, $\Delta M/\Gamma$, has the following CKM-angle dependence:

$$\frac{\Delta M}{\Gamma}(B_d^0) \leq \lambda^2$$

$$\frac{\Delta M}{\Gamma}(B_s^0) \propto \frac{\lambda^4}{\lambda^4} = 1 \qquad (6)$$

This gives a simple pattern, namely mass-mixing in the B_d^0 - $\bar{B}_d^0$ system is CKM forbidden, while in the B_s^0 - $\bar{B}_s^0$ system it is CKM allowed. The reason for this selection rule is nothing else but the experimental suppression of the $b \to u$

transition compared to the b→c transition. Theoretical estimates for $f_{Bd} \cdot \hat{B}$ and the present bound on $\overline{R}$ give $\Delta M/\Gamma(B_d^0) \leq 10^{-2}$. The numerical predictions for the quantity $\Delta M/\Gamma(B_s^0)$ are somewhat model dependent due to the unknown constants f_{Bs} and $\hat{B}$. Theoretical estimates for f_{Bs} differ by a factor ~ 2 in literature 12,13). I will use the value $f_{Bs} \simeq 200$ MeV (to be compared with $f_\pi \simeq 130$ MeV and $f_k = 164$ MeV) derived in ref. (13) based on a non-relativistic quark model calculation. It is likely that $\hat{B}$ for the bottom mesons is close to 1. The general expectations are that $\Delta M/\Gamma(B_s^0) \geq 1$ and it could be as large as 3 - 4 [7,11,13]. The life-time differences $\Delta\Gamma/\Gamma$ are expected to be small in both the B_d^0 - $\overline{B}_d^0$ and B_s^0 - $\overline{B}_s^0$ systems and we neglect them here. Before leaving the theoretical discussion perhaps one should also mention that the scenario $\Delta M/\Gamma(B_d^0) \leq 10^{-2}$ is specific to the CKM model. In supersymmetric extensions of the standard model the gluino induced flavour mixing couplings e. g. $b_L\, \tilde{g}(\tilde{d}_L, \tilde{s}_L, \tilde{b}_L)$ lead to additional contributions to $\Delta M(B_d^0)$ and $\Delta M(B_s^0)$[14]. Typically[15], one gets (for both the real and imaginary parts separately)

$$\frac{(\Delta M)\ \mathrm{SUSY} - \tilde{g}\ \mathrm{box}}{(\Delta M)\ \mathrm{standard\ model}} \simeq \frac{22}{27}\, \frac{\alpha_s^2(m_{\tilde{g}}^2)}{\alpha_2^2}\, f'(m_{\tilde{g}}^2/m_{\tilde{s}}^2)\, \frac{m_t^2}{m_{\tilde{s}}^2} \tag{7}$$

where α_s and α_2 are, respectively, the QCD and $SU(2)_L$ coupling constants and $f'(z)$ is the function $f'(z) \equiv 2 \int_0^1 d_X(x^3(1-x)/(x+z(1-x)^3)$, which takes the value 1 for $z = 0$ and 1/10 for $z = 1$. The alignment of the large-$\not{p}_T$ events in the UA1 data[16] with the standard model implies[17] that most probably the supersymmetric scalar particles are very massive and the function $f'(m_{\tilde{g}}^2/m_{\tilde{s}}^2) m_t^2/m_{\tilde{s}}^2 << 1$. The possible augmentation of the standard model contribution for $\Delta M/\Gamma$ (B_d^0) in the SUSY-extensions is something to be kept at the back of our mind. I will, however, restrict myself in this talk to the standard model predictions.

B - $\overline{B}$ Oscillations: Phenomenology

Primary charged leptons in the decays $b \to \ell^- \overline{\nu}_\ell X$ have become a standard tool in tagging the bottom quark. Measurements of the semileptonic brancning ratios in e^+e^- continuum using energetic $\ell^\pm$ ($\ell = e, \mu$) have yielded results, which are close to the corresponding measurements at the $\Upsilon(4S)$ resonance, where $b\overline{b}$ quarks are produced relatively abundantly[3]. Thus, leptons are good flavour tags and the obvious signature of B - $\overline{B}$ oscillations is to look for the "wrong-sign lepton" in the decays $B \to \ell^+ \nu_\ell X$ [7,8]. Of course, ℓ^+ can be produced by the normal (i. e. unmixed) decays of the bottom hadrons via the cascade $b \to cx$,
$\to \ell^+ \nu_\ell X$

as well as from the normal charm decays, $c \to \ell^+ \nu_\ell X$, and we shall assume that reliable estimates of these backgrounds are available.

Let us define a quantity which we take as a measure of B - $\overline{B}$ mixings, $\chi \equiv \Gamma(B \to \ell^+ X)/\Gamma(B \to \ell^\pm X)$[18], where Γ is the total time integrated rate. Then, if the predicted dilepton rate from the primary B decays is denoted by $N_{2\ell}$, the expected rate for opposite and same charge combination is $N_{+-} = ((1-\chi)^2 + \chi^2) N_{2\ell}$ and $N_{\pm\pm} = 2\chi(1-\chi) N_{2\ell}$. One can explicitly relate χ to the mixing parameters for the B_d^0 and B_s^0 mesons, $\chi_{d(s)} = \Gamma(B_{d(s)}^0 \to \ell^+ X)/\Gamma(B_{d(s)}^0 \to \ell^\pm X)$, via the relation

$$\chi = \frac{(BR)_d}{\langle BR \rangle} P_d \chi_d + \frac{(BR)_s P_s \chi_s}{\langle BR \rangle} \tag{8}$$

where P_d (P_s) is the fraction of B_d^0 (B_s^0) meson production in b quark fragmentation, $(BR)_d$ $[(BR)_s]$ is the semileptonic branching ratio for the B_d^0 (B_s^0) meson and $\langle BR \rangle$ is the average semileptonic branching ratio of bottom hadrons measured in the continuum. Following the discussion in the last section we set $\chi_d = 0$ in Eq. (8) which gives

$$\chi \simeq \frac{(BR)_s P_s \chi_s}{\langle BR \rangle} \simeq P_s \chi_s \simeq f(s\overline{s})\, \chi_s \tag{9}$$

where the last two equalities emerge from the assumption (i) $(BR)_s \simeq \langle BR \rangle$ and (ii) $P_s \simeq f(s\overline{s})$, which is the probability of producing an $s\overline{s}$ pair in the fragmentation of the b-quark jet. The quantity $f(s\overline{s})$ has been measured by a large number of experimental groups at PETRA and PEP[20] and at the CERN collider by the UA(N) Collaborations[21]. Typical range of values for $f(s\overline{s})$ are [20,21]

$$\begin{aligned} f(s\overline{s}) &= 0.1 - 0.15 \qquad \mathrm{PEP/PETRA} \\ &= 0.12 - 0.20 \qquad \mathrm{CERN\ Collider} \end{aligned} \tag{10}$$

The fraction $f(s\overline{s})$ is increasing with $\sqrt{s}$ in e^+e^- annihilation. In hadron-hadron collisions it may have a larger value in large-P_T jets compared to the diffractive and single non-diffractive events. A good measure of $f(s\overline{s})$ for neavy quark jets would be available if one could experimentally measure the ratio $\sigma(F^\pm)/\sigma(D)$ in e^+e^- and/or $\overline{p}p$ collisions.

The quantity χ_s in Eq. (9) can be calculated theoretically. Defining by r_s the ratio of wrong-sign to right-sign leptons in the B_s^0 decays,

$$r_s \equiv \frac{\Gamma(B_s^0 \to \ell^+ \nu_\ell X^-)}{\Gamma(B_s^0 \to \ell^- \bar{\nu}_\ell X^+)}$$

(r_s is related to χ_s defined earlier by $\chi_s = r_s/(1 + r_s)$) one gets the relation[8]:

$$r_s = [(\Delta M/\Gamma)^2 + (\Delta\Gamma/2\Gamma)^2]/[2 + (\Delta M/\Gamma)^2 - (\Delta\Gamma/\Gamma)^2]$$

$$\underset{\Delta\Gamma/\Gamma \ll 1}{\simeq} \frac{(\Delta M/\Gamma)^2}{2 + (\Delta M/\Gamma)^2} \underset{\Delta M/\Gamma \gg 1}{\to} 1 \tag{11}$$

Most theoretical calculations[7,11,13] predict $1 \le \Delta M/\Gamma \le 4$ for $m_t \simeq 40$ GeV giving $0.33 \le r_s \le 0.9$. Thus, a very significant fraction of wrong-sign leptons are expected in case of B_s^0 decays. The ratio of same-sign to opposite-sign dileptons can be expressed as follows

$$\frac{N_{\pm\pm}}{N_{+-}} = \frac{2\,\chi(1-\chi)}{(1-\chi^2)+\chi^2}$$

$$\simeq \frac{2\,f(s\bar{s})\,r_s(1 + r_s - f(s\bar{s})\,r_s)}{(1 + r_s - f(s\bar{s})\,r_s)^2 + r_s^2\,f^2(s\bar{s})} \tag{12}$$

$$\underset{r_s \to 1}{\to} \frac{2\,f(s\bar{s})\,(2 - f(s\bar{s}))}{(2 - f(s\bar{s}))^2 + f^2(ss)}$$

$$\simeq 0.15 - 0.22 \text{ for } f(s\bar{s}) \simeq 0.15 - 0.20$$

To compare the above ratio with data one should add to this the contributions due to the bottom hadron semileptonic cascades, which obviously depend on the specific experimental conditions.

Since the mixing is expected to be significant in the $B_s^0 - \bar{B}_s^0$ sector alone, there are a number of additional correlations due to the left over strange quark in the bottom fragmentation process and the primary lepton $\ell^\pm$ in the primary B

decays

$$\begin{array}{l} b \to (b\bar{s}) + s \\ \quad\updownarrow \qquad\quad \to (\Lambda^0, K^-, K^{*-}) \\ (\bar{b}s) \to \ell^+ X \end{array} \tag{13}$$

giving rise to final states of the form $\ell^+ \ell^+ \Lambda^0$, $\ell^- \ell^- \bar{\Lambda}^0$ [13] as well as $\ell^+ K^- K^-$, $\ell^- K^+ K^+$ in the b quark-jet [22]. The $\ell^\pm K^\mp K^\mp$ final states in the same-jet also provide a very clean signature of $B_s^0 - \bar{B}_s^0$ mixing and they may even be better, as far as counting rates are concerned, for those detectors which have good particle identification.

Yet another place to detect the presence of $|\Delta B| = 2$, $|\Delta Q| = 0$ transitions is the electroweak forward-backward charge asymmetry in the reaction $e^+e^- \to b\bar{b}$ [10]. The standard expression in the absence of B-$\bar{B}$ mixings is well known. For $s \ll m_Z^2$ one has

$$A_{FB}^b = \frac{-3\,g_A^e\,g_A^b}{8\,Q_b\,\sin^2\theta_W\,\cos^2\theta_W}\;\frac{s}{s - m_Z^2} \tag{14}$$

where $g_A^b(Q_b)$ is the axial coupling (electric charge) of the b quark and g_A^e is the axial coupling for the electron. Note that g_A^b is the same for b and $\bar{b}$ but Q_b has opposite sign. Since normally the charge asymmetry in $e^+e^- \to b\bar{b}$ is measured via the final state $e^+e^- \to \ell^\pm X$, involving a b quark semileptonic decay, the presence of B - $\bar{B}$ mixings, which lead to wrong-sign leptons, will decrease this asymmetry. More precisely, measured asymmetry, $\bar{A}_{FB}^b$, is related to A_{FB}^b defined above by the relation

$$\bar{A}_{FB}^b(e^+e^- \to b\,\bar{b} \to \ell^- X) = \left[\frac{BR(b \to \ell^- X) - BR(\bar{b} \to \ell^- X)}{\langle BR \rangle}\right] A_{FB}^b$$

$$= (1 - 2\,\chi)\,A_{FB}^b \tag{15}$$

$$\simeq \left(1 - \frac{2\,f(s\bar{s})\,r_s}{1 + r_s}\right) A_{FB}^b$$

$$\underset{r_s \to 1}{\to} 1 - f(s\bar{s}) \quad A_{FB}^b$$

Thus, for complete Bs-$\bar{B}$s mixing, the ratio $\bar{A}^b_{FB}/A^b_{FB}$ is smaller than 1 by the fraction $f(s\bar{s})$. We expect $f(s\bar{s}) \simeq 0.15$ at PETRA/PEP energies.

Comparison with data

Let us concentrate on the dimuon data first. Summarising the 1983 + 1984 UA1 dimuon data, a total of 208 $\mu^\pm\mu^\pm$, $\mu^+\mu^-$ events have been observed which survive the cuts $P^\mu_T > 3$ GeV and $m_{\mu\mu} > 6$ GeV[9]. After subtracting the usual backgrounds and the contributions from Drell-Yan processes, $\Upsilon \to \mu^+\mu^-$ and $Z^0 \to \mu^+\mu^-$, 163 $\mu\mu$ events survive. These are expected to be mainly due to heavy quark pair production processes $p\bar{p} \to c\bar{c}$, $b\bar{b}$, $t\bar{t} \to \mu\mu x$, with the $b\bar{b}$ being the dominant source, estimated to be ~ 80 % [13,23]. A comparison of a QCD based model[24], which includes the 2→2 and 2→3 heavy flavour production processes[25], with the UA1 data for $p\bar{p} \to \mu x$ and $p\bar{p} \to \mu\mu x$ [26] is shown in fig. 1. It is fair to conclude from this comparison that perturbative QCD describes the large-P_T heavy flavour production in $\bar{p}p$ collisions rather well.

Based on the $\mu\mu x$ data and the theoretical model of ref. 24 the UA1 collaboration has estimated the bottom quark pair production cross-section at $\sqrt{s} = 630$ GeV [9].

$$\sigma(p\bar{p} \to b\bar{b}x) = 1.5 \pm 1.0 \text{ (syst.) } \mu b \quad \text{for } P^b_T > 5 \text{ GeV}, \quad |\eta^b| < 2.0$$

In comparison, theoretical estimates for $b\bar{b}$ production cross-section in e^+e^- annihilation give $\sigma(e^+e^- \to b\bar{b}x) = 34\ (29 \text{ GeV}/\sqrt{s})^2$ Pb, thereby yielding a relative factor (between $s\bar{p}PS$ and PEP energies)

$$\frac{\sigma(p\,\bar{p} \to b\bar{b}x)}{\sigma(e^+e^- \to b\bar{b}x)} \geq 4.4 \times 10^4$$

Returning to the analysis of the UA1 $\mu\mu x$ data, the ratios of same-sign to opposite-sign dimuons reported by Watkins are[9]:

$$R\left(\begin{array}{l}\underline{++}\,/\,+-\\ \text{all events}\\ \text{Drell-Yan, }\Upsilon\text{ subtracted}\end{array}\right) = \frac{59}{104} = 0.56 \pm 0.09$$

$$R\left(\begin{array}{l}\underline{++}\,/\,+-\\ \text{non-isolated}\end{array}\right) = \frac{44}{83} = 0.53 \pm 0.10$$

where the so-called non-isolated data sample is defined by the requirement of hadronic energy deposition with $E_T > 4$ GeV in a cone of angular size $\Delta R \equiv \Delta\eta^2 + \Delta\phi^2$

< 0.7, centered around one of the muons ($\Delta\eta$ = pseudorapidity size and $\Delta\phi$ = azimuthal angle size of the cone.) Thus, the requirement of isolation does not change the ratio $R(\pm\pm/+-)$ within the statistical error. The ratios quoted above include contributions from the processes $p\bar{p} \to c\bar{c}$, $b\bar{b}$, $t\bar{t} \to \mu\mu x$, and in particular the same-sign dimuons recieve a significant contribution from the process

$$\begin{array}{l} p\bar{p} \to b\bar{b} \qquad + (c \cdot c), \\ \quad\ \to \ell^+ \\ \quad\ \to c \to \ell^+ \end{array}$$

involving a primary and a secondary bottom hadron semileptonic decay. Using the so-called EUROJET Monte Calro[24] and the UA1 acceptance one gets $R(\pm\pm/--) \simeq 0.32$ without B-$\bar{B}$ mixing. Another independent theoretical calculations[23] gives $R(\pm\pm/+-) = 0.33$. Thus, clearly there is an excess of same-sign dimuon events in the present UA1 data. Using $r_s = 1$, corresponding to maximum mixing in the Bs-$\bar{B}$s system, and $f(s\bar{s}) = 0.20$, which probably is an upper bound for the ratio $\sigma(p\bar{p} \to B^0_s x)/\sigma(p\bar{p} \to Bx)$ at the CERN collider energies, the EUROJET[24] Monte Carlo predicts $R(\pm\pm/+-) \simeq 0.53$, a number which is in good agreement with the UA1 data. Thus, taking the UA1 data on its face value would imply almost complete Bs-$\bar{B}$s mixing.

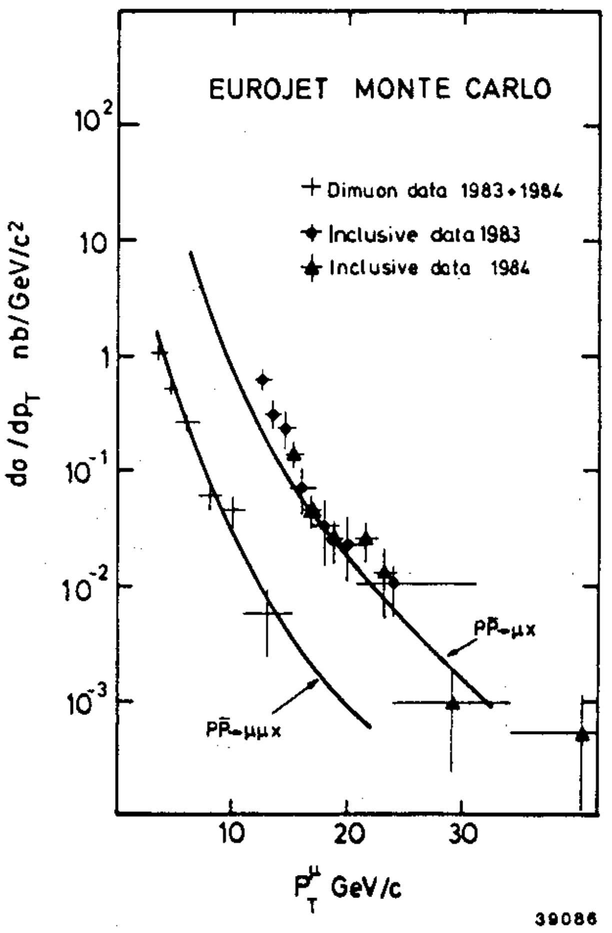

Fig. 1: A comparison of the processes $p\bar{p} \to \mu x$ and $p\bar{p} \to \mu\mu x$, measured by the UA1 Collaboration at the CERN $p\bar{p}$ collider, with the pert. QCD calculations of ref. 24

Interpreting an effect which has only a 2.5 σ statistical significance is a dangerous excercise! Clearly more data are needed before definitive conclusions could be reached. Nevertheless, it is tempting to use the measured value of $R(\pm\pm/+-)$ and the QCD based estimates for the background, and set a lower bound on the B-$\bar{B}$ mixing measure χ. At the 90 % C.L., the present UA1 data and the EUROJET model calculations lead to a lower bound $\chi \geq 0.04$. In fig. 2, we show contours of constant χ in a two-dimensional $f(s\bar{s})$ - r_s plot. For $f(s\bar{s}) \leq 0.2$, for example, one gets a lower bound on the Bs-$\bar{B}$s mixing measure r_s, $r_s \geq 0.25$.

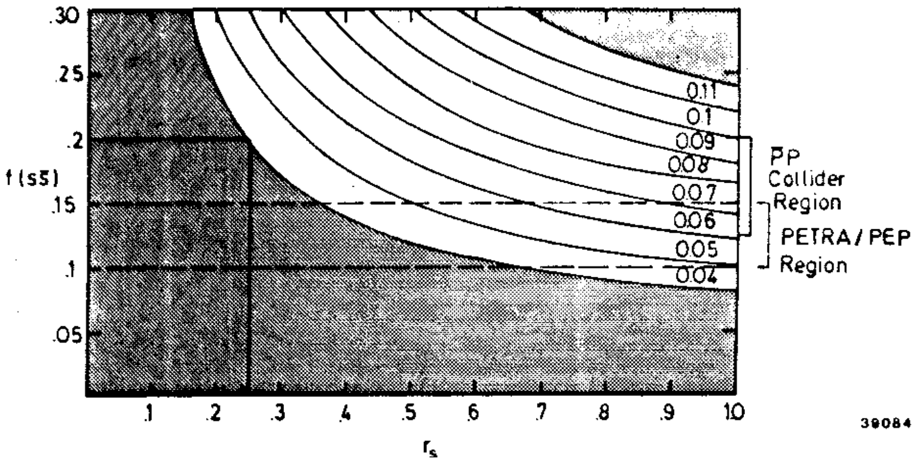

Fig. 2: Contours of constant χ in the $f(ss)$ - r_s plane. The shaded area on the upper right hand corner is excluded by the MARK-II upper limit $\chi \leq 0.12$ [19]. The 90 % C.L. lower limit from the UA1 data[5], $\chi > 0.04$, excludes the left hand shaded area. The most likely regions of $f(s\bar{s})$ for PETRA/PEP and collider data are also indicated.

From e^+e^- annihilation, there are two null results available on B-$\bar{B}$ mixing, which are based on dilepton final states. The CLEO Collaboration[27] has set an upper limit on the dilepton ratio, $Y_{B_d^0} = (N_{B_d^0 B_d^0} + N_{\bar{B}_d^0 \bar{B}_d^0})/N_{B_d^0 \bar{B}_d^0} = N^{\pm\pm}/N^{+-}$. The limit set is $Y_{B_d^0} < 0.30$ at the 90 % C.L. As discussed in the previous section, the quantity B_d^0 is CKM suppressed and hence expected to be negligibly small in the standard model. In addition to the CKM suppression, there is an additional suppression expected at the $\Upsilon(4s)$ resonance, since there the B mesons are produced in an $\ell = 1$ state, and the resulting interference effects provide an additional suppression[28]. The other upper bound has been set by the MARK-II Collaboration[19], which is based on the measurement of dilepton rates in the process $e^+e^- \rightarrow$ hadrons at $\sqrt{s} = 29$ GeV. They find the measured dilepton rates to be in good agreement with predictions based on the standard charm and bottom hadron semileptonic decays. The quoted upper limit is $\chi < 0.12$ at 90 % C.L.

In fig. 2 we show the area excluded by the MARK-II data on the $f(s\bar{s})$ - r_s plot. It is clear that the e^+e^- data do not yet have the statistical significance to put a meaningful limit on the mixing parameters in the standard model. Using $f(s\bar{s}) \leq 0.15$, which is a remarkably stable number in almost all e^+e^- measurements[20], we see that a sensitivity of $\chi \leq 0.07$ is needed to test even the $r_s = 1$ limit (i. e. maximum Bs-$\bar{B}$s mixing.)

Yet another limit on B-$\bar{B}$ mixing is due to searches for possible reduction in the electroweak charge asymmetry in the process $e^+e^- \rightarrow b\bar{b} \rightarrow \ell^\pm X$ [10]. Measurments of the bottom quark asymmetry, in my opinion, are still in their initial phase. Precision measurements of charge asymmetry demand large statistics at the highest possible PETRA energies, where unfortunately the present data samples are rather modest.

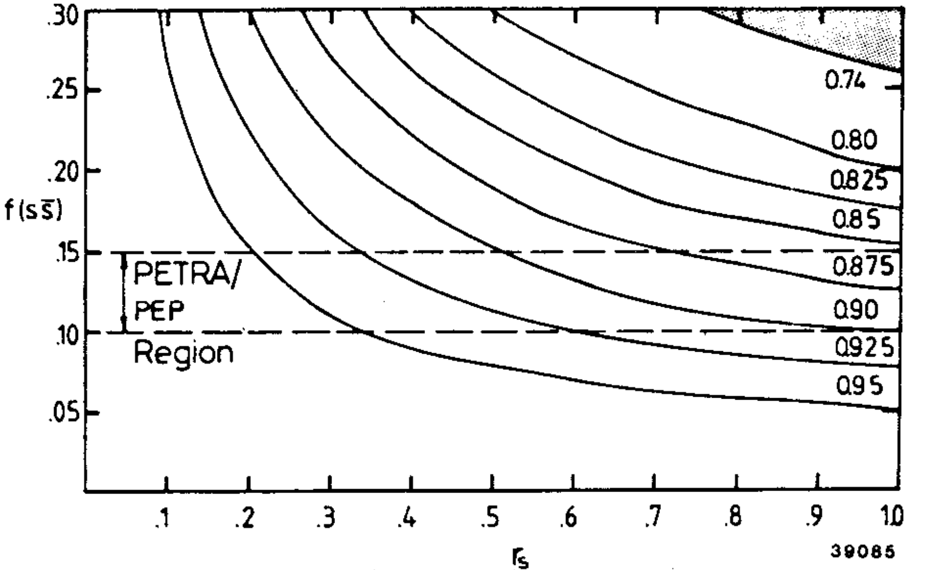

Fig. 3: Contours of constant $R^b_{asym} = \bar{A}^b_{FB}/A^b_{FB}$ in the $f(s\bar{s})$ - r_s plane. The shaded area on the upper right hand corner is excluded by the electroweak charge asymmetry measurements $\bar{A}^b_{FB} \geq 0.74$ (90 % C.L.) at DESY. The most likely region of $f(s\bar{s})$ at PETRA/PEP energies is also indicated.

Despite this the JADE Collaboration at DESY[10)] has been able to measure bottom quark charge asymmetries at a respectable (~4σ) level. Combining all the PETRA data[29)] yields at 90 % C.L. $R^b_{asym.} < 0.74$, where the reduction factor is difined in Eq. 16:

$$R^b_{asym.} \equiv \bar{A}^b_{fB}/A^b_{f_B} = (1 - 2\chi)$$

In fig. 3 we draw contours for constant $R^b_{asym.}$ using the equation $R^b_{asym.} = 1 - (2 f(s\bar{s})\, r_s)/(1 + r_s)$, with the boundary condition $0 \leq r_s \leq 1$ and $0 \leq f(s\bar{s}) \leq 0.3$. Also shown is the excluded region for $R^b_{asym.} < 0.74$ (corresponding to $\chi < 0.13$). This limit is slightly worse than the one set by tne MARK-II dimuon data $\chi < 0.12$. Again, the expected effect at PETRA/PEP for $f(s\bar{s}) \leq 0.15$ and $r_s \simeq 1$ is $R^b_{asym.} \geq 0.86$ (i. e. $\chi \leq 0.07$).

In conclusion, there is some preliminary evidence for B-$\bar{B}$ mixings in the CERN collider data, though it does not yet have the impeachable 5σ character. We wait eagerly for the results from the fall '85 run of the collider. Experiments in e^+e^- annihilation have so far provided null results which do not yet test the standard model in the interesting region of the parameter space. This situation, however, may change in not too distant a future. Let us hope that the ongoing PETRA/PEP and CESR/DORIS runs, and the anticipated high energy runs at the planned e^+e^- machines LEP, SLC and TRISTAN would probe the standard model predictions for B-$\bar{B}$ mixings in a non-trivial way.

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