Ref.TH.3896-CERN
ITP Univ. of Stockholm
Preprint No. 1, April 1984

SIGNATURES OF $B_s^0 - \bar{B}_s^0$ MIXINGS IN $p\bar{p}$ AND e^+e^- COLLISIONS

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ABSTRACT

Recent measurements of the bottom meson lifetime and upper limit on the ratio $\Gamma(b \rightarrow u\ell\nu) / \Gamma(b \rightarrow c\ell\nu)$ have strengthened the hope of large mixing between the neutral bottom mesons $B_s^0 - \bar{B}_s^0$. We investigate the consequences of such a mixing in e^+e^- annihilation and $p\bar{p}$ collisions and estimate dimuon rates and backgrounds from various sources. We point out that the recent UA1 dimuon data hint at a substantial mixing in the $B_s^0 - \bar{B}_s^0$ sector.

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Recent measurements of the bottom meson lifetime $\tau_B^{(1)}$, τ_B , and the upper bound $\bar{R}^{(2)}$ on the semileptonic ratio $\bar{R} \equiv \Gamma(b \rightarrow u \ell \nu) / \Gamma(b \rightarrow c \ell \nu)$ have considerably constrained the parameters of the Cabibbo - Kobayashi - Maskawa matrix $^{(3)}$. The present value for τ_B

$$\tau_B = (1.4 \pm 0.3 \pm 0.3) 10^{-12} \text{ sec} \quad (1)$$

and the bound

$$\bar{R} \leq 0.03 \quad (2)$$

can be transcribed as information on the elements of the K - M matrix giving

$$|V_{cb}| = 0.05 \pm 0.01, \quad \left| \frac{V_{ub}}{V_{cb}} \right| < 0.12. \quad (3)$$

Thus, the present knowledge on the weak transitions can be conveniently parametrized in a matrix form given by Wolfenstein $^{(4)}$. To $\mathcal{O}(\lambda^3)$ one has,

$$V = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} \quad (4)$$

where

$$\lambda \equiv \sin \theta_c = 0.23, \quad A = 1.0 \pm 0.2, \quad \rho^2 + \eta^2 < 0.3.$$

The parametrization (4) has the simple (and easy to remember) features that the elements V_{ud} and V_{cd} have the same interpretation (to $\mathcal{O}(\lambda^3)$) as in the old Cabibbo - GIM matrix, $|V_{cb}| = |V_{ts}|$, and the CP violation enters at $\mathcal{O}(\lambda^3)$.

The possibility of observable weak interaction mixings among the neutral bottom meson systems $B_d^0 - \bar{B}_d^0$ and $B_s^0 - \bar{B}_s^0$ has been entertained in the literature $^{(5)}$ ever since the discovery of the bottom quark $^{(6)}$. The new experimental information excludes the possibility of a significant mixing in the $B_d^0 - \bar{B}_d^0$ system but indicates a very sizeable mixing in the $B_s^0 - \bar{B}_s^0$ sector. Recent theoretical updates $^{(7)}$ confirm the earlier estimates $^{(5)}$ and in the rest of this paper we shall just concentrate on the $B_s^0 - \bar{B}_s^0$ mixing and investigate its consequences for e^+e^- and $p\bar{p}$ collisions. However, before we present the details of our calculation it is worth pointing out that the bottom meson B_s^0 has not yet been discovered and it is particularly amusing that the consequences of an unobserved particle are expected to show up earlier than the discovery of the particle itself!

The main motivation of this paper stems from the QCD estimates of a rather large observable cross-section for the process $p + \bar{p} \rightarrow b + \bar{b} + x$ at the present CERN collider. Since the data from CESR and DORIS are mainly concentrated in a region $\sqrt{s} \leq m(Y(4s))$ where the B_S^0 meson production is excluded, and the $e^+e^- \rightarrow b\bar{b}$ cross-section at PETRA/PEP energies is a small fraction of the total hadronic cross-section, we do not expect any sizeable mixing effects in the present e^+e^- data. This situation will, however, change at the z^0 peak.

We start with a discussion of the relevant mixing parameters. The quantities of theoretical interest are the meson mass difference ΔM and the width differences $\Delta\Gamma$. Defining the mass eigenstates of the bottom mesons consisting of the $b\bar{s}$ and $\bar{b}s$ quarks by [F1]

$$B_{H,L}^0 = \frac{1}{\sqrt{2}} (B_S^0 \pm \bar{B}_S^0)$$

we introduce ΔM and $\Delta\Gamma$ by

$$\begin{aligned} \Delta M &\equiv M_H - M_L \\ \Delta\Gamma &\equiv \Gamma_H - \Gamma_L \end{aligned} \quad (5)$$

The quantities ΔM and $\Delta\Gamma$ are calculated in terms of Γ_{12} and M_{12} defined via the equation

$$H \begin{pmatrix} B_S^0 \\ \bar{B}_S^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i}{2}\Gamma & M_{12} - \frac{i}{2}\Gamma_{12} \\ M_{12}^* - \frac{i}{2}\Gamma_{12}^* & M - \frac{i}{2}\Gamma \end{pmatrix} \begin{pmatrix} B_S^0 \\ \bar{B}_S^0 \end{pmatrix} \quad (6)$$

one then has

$$\begin{aligned} \Delta M &= 2 \operatorname{Re} \sqrt{(M_{12} - \frac{i}{2}\Gamma_{12})(M_{12}^* - \frac{i}{2}\Gamma_{12}^*)} \\ \Delta\Gamma &= -4 \operatorname{Im} \sqrt{(M_{12} - \frac{i}{2}\Gamma_{12})(M_{12}^* - \frac{i}{2}\Gamma_{12}^*)} \end{aligned} \quad (7)$$

M_{12} and Γ_{12} are calculated usually by the Box diagrams and the results are by now well-known. An excellent approximation of the mass difference is ⁽⁷⁾:

$$M_{12}(B_S) = \frac{G_F^2 \cdot B \cdot f_{B_S}^2 m_{B_S} M_W^2}{12 \pi^2} \lambda_t^2 u_2 \tau_2^B \quad (8)$$

where $\mathcal{B}$ is the bag constant ($= 1$ in the vacuum insertion approximation), f_{B_s} is the pseudoscalar coupling constant (analogue of the pion coupling constant $f_\pi = 130$ MeV), $\lambda_t^S = A\lambda^2 = 0.05 \pm .01$, η_2^B is a QCD-correction factor (≈ 0.8) and U_2 is a function of the quark masses $U_2 = U_2(m_b, m_t, m_s)$. An approximate expression for U_2 is ⁽⁵⁾

$$U_2 \approx \frac{m_t^2}{m_W^2} \left(1 + \frac{1}{3} \frac{m_b^2}{m_t^2} + \frac{3}{4} \frac{m_b^2}{m_t^2} \ln \left(\frac{m_t^2}{m_b^2} \right) \right) \stackrel{m_t \approx 40 \text{ GeV}}{\approx} 0.25$$

where terms of $O(m_b^4/m_t^4)$ and $O(m_t^4/m_W^4)$ have been neglected. Buras et al. ⁽⁷⁾ have calculated the function U_2 exactly and obtain

$$U_2 = 0.23$$

It is worth pointing out that M_{12} is a "top-meter". However, the biggest uncertainty in M_{12} stems from an imprecise knowledge of the constants $\mathcal{B}$ and f_{B_s} . In the following we estimate f_{B_s} using a non-relativistic potential model approach, an approximation which should reasonably work for the B_s^0 meson. Defining

$$\langle 0 | \bar{b} \gamma_\lambda \gamma_5 s | B_s^0(q) \rangle \equiv i f_{B_s} \cdot q_\lambda$$

the constant f_{B_s} can be related to the wave-function at the origin $\psi(0)$ via the relation ⁽⁸⁾

$$f_{B_s} = \sqrt{\frac{12}{m_{B_s}}} \psi_{B_s}(0). \quad (9)$$

Thus, the particular combination $f_{B_s}^2 m_{B_s}$ entering in Eq. (8) is given by

$$f_{B_s}^2 m_{B_s} = 12 |\psi_{B_s}(0)|^2. \quad (10)$$

We calculate $|\psi_{B_s}(0)|$ by relating it to the wave-function of the $Y(1s)$, $\psi_Y(0)$. Using the ^S empirical result that $\psi(0) \propto m_Q$ (giving

$$\frac{1}{f_Q^2} \Gamma(V(Q\bar{Q}) \rightarrow e^+e^-) = \text{Const. which is in excellent agreement with the data) and$$

generalizing it to the present case in the form $\psi(0) \propto \mu_q$ where μ_q is the reduced mass gives,

$$|\psi_{B_s}(0)| = \frac{2m_s}{m_b + m_s} |\psi_Y(0)|. \quad (11)$$

The QCD (one-loop) - corrected value for $|\psi_Y(0)|$ from $\Gamma(Y \rightarrow e^+ e^-)$ is $|\psi_Y(0)|^2 = 0.52 \pm 0.02 \text{ GeV}^3$. The relation (11) then leads to the following estimate (for $m_b = 4.8 \text{ GeV}$, $m_s = 0.5 \text{ GeV}$)

$$f_{B_s}^2 m_{B_s} = 12 |\psi_{B_s}(0)|^2 = 0.22 \text{ GeV}^3 \quad (12)$$

which for $m_B = 5.4 \text{ GeV}$ gives $f_{B_s} = 200 \text{ MeV}$, a number not too different from the existing estimates for f_F and f_D . Using (12) we get (leaving the bag constant $\mathcal{B}$ as a free parameter)

$$M_{12}(B_s^0) = 6.8 \times 10^{-13} (\mathcal{B}) \text{ GeV}. \quad (13)$$

Thus $\Delta M(B_s^0)$ turns out to be at least two orders of magnitude bigger than $\Delta M(K_S - K_L)$. Next, we determine the quantity

$$\frac{\Delta M}{\Gamma_{B_s}} \approx 2 \frac{|M_{12}|}{\Gamma}.$$

One could use the free quark decay to estimate Γ_B or else use the measured life-time τ_B . In the first case, there is considerable uncertainty due to imprecise determination of the b-quark mass since $\Gamma \sim m_b^5$. In using $\langle \tau_B \rangle$ measured, however, one doesn't really know the spread in the values for $\tau_{B_d^0}$, B_u^+ , B_s^0 , though unlike charm meson lifetimes they are not expected to disperse widely. In Table 1 we present $\Delta M/\Gamma_B$ for the $\pm 1\sigma$ spread in τ_B for $\mathcal{B} = 0.5$ and 1.0 . For all values of τ_B and $\mathcal{B}$ in table 1 we find that the mixing parameter $\frac{\Delta M}{\Gamma}(B_s^0) > 1$. On the other hand the life-time difference $\Delta\Gamma$ is small for the $B_s^0 - \bar{B}_s^0$ meson as well. There exists a general consensus in the literature^(5, 7) that $\Delta\Gamma/\Delta M(B_s^0) \ll 1$ and so we shall ignore $\Delta\Gamma$.

Next we discuss the consequences of the $B_s^0 - \bar{B}_s^0$ mixing for the $p\bar{p}$ and e^+e^- collisions. We shall concentrate on time integrated quantities⁽⁵⁾ since the short life-time for the bottom mesons does not allow a $K_S - K_L$ regeneration type experiment. In particular we shall concentrate on the primary semileptonic decays $b \rightarrow c \ell \bar{\nu}_\ell$ and in the first part assume that it is possible in an experiment to effectively remove the secondary leptons from the decay $b \rightarrow c \rightarrow \ell^+$, by, for example, using a large transverse

momentum cut on the lepton. To that end we recall the definition of the measure of weak mixing in the semileptonic decays^{(5), (9)}

$$r \equiv \frac{\Gamma(B_s^0 \rightarrow \ell^+ \nu X^-)}{\Gamma(B_s^0 \rightarrow \ell^- \bar{\nu} X^+)} = \frac{(\frac{\Delta M}{r})^2 + (\frac{\Delta \Gamma}{2r})^2}{2 + (\frac{\Delta M}{r})^2 - (\frac{\Delta \Gamma}{2r})^2} \quad (14)$$

$$\approx (\frac{\Delta M}{r})^2 / (2 + (\frac{\Delta M}{r})^2) .$$

The fractions of the "wrong-sign" and "right-sign" leptons in the B_s^0 decays are then given by

$$\frac{\Gamma(B_s^0 \rightarrow \ell^+ \nu X^-)}{\Gamma_{SL}(B_s^0)} = \frac{r}{r+1} , \quad \frac{\Gamma(B_s^0 \rightarrow \ell^- \bar{\nu} X^+)}{\Gamma_{SL}(B_s^0)} = \frac{1}{r+1} . \quad (15)$$

Since we are mainly concerned with the continuum e^+e^- and $p\bar{p}$ physics and the mixing is expected only in the $B_s^0 - \bar{B}_s^0$ case one has to estimate (or better measure) the relative probability, κ , of exciting an $s\bar{s}$ pair from the vacuum in the environment of an excited quark or gluon,

$$\frac{b \rightarrow B_s^0}{b \rightarrow \text{all}} \sim \frac{| \langle 0 | s\bar{s} \rangle |_{(q^*, G^*)}^2}{\sum_q | \langle 0 | q\bar{q}, q\bar{q}, \dots \rangle |_{(q^*, G^*)}^2} \equiv \kappa \quad (16)$$

The $s\bar{s}$ - density κ is a function of Q^2 , the virtuality of the quark or gluon in whose colour field the $q\bar{q}$ pairs are produced. $\kappa(Q^2)$ is an increasing function of Q^2 and should reach an asymptotic value when the $s\bar{s}$ quark pair mass could be completely neglected (The asymptotic SU(3) limit for κ being $\sim 1/3$). Recent measurement of κ by the TASSO collaboration⁽¹⁰⁾ gives

$$\kappa(Q = 18 \text{ GeV}) \simeq 0.16 . \quad (17)$$

In comparison to e^+e^- data the typical energy of the b-quark jet in the process $p + \bar{p} \rightarrow b + \bar{b} + x$ at the present collider corresponds to an average Q-value $\langle Q \rangle = \langle E_{\text{jet}} \rangle \simeq 35 \text{ GeV}^{(11)}$. Thus we expect $\kappa(Q^2)$ to be considerably larger at the $p\bar{p}$ collider energies than at PETRA energies. Combining (15) and (16) one gets [F2].

$$\begin{aligned}
 BR(b \rightarrow \ell^+ X^-) &= \kappa \frac{r}{r+1} B_{SL}(b) \\
 BR(b \rightarrow \ell^- \bar{\nu} X^+) &= \left[1 - \kappa + \frac{\kappa}{r+1} \right] B_{SL}(b)
 \end{aligned} \tag{18}$$

which leads to the ratio

$$\begin{aligned}
 R_{\ell\ell}(b\bar{b}) &\equiv \frac{\sigma(P\bar{P} \xrightarrow{e^+e^-} b\bar{b} \rightarrow \ell^+\ell^+ + \ell^-\ell^-)}{\sigma(P\bar{P}, e^+e^- \rightarrow \ell^+\ell^-)} = \frac{2\kappa r[(1-\kappa)(r+1) + \kappa]}{\kappa^2 r^2 + [(1-\kappa)(r+1) + \kappa]^2} \tag{19} \\
 &\xrightarrow[r=1]{\kappa=\frac{1}{3}} \frac{2\kappa(2-\kappa)}{\kappa^2 + (2-\kappa)^2} \xrightarrow{\kappa=\frac{1}{3}} \frac{10}{26} . \tag{20}
 \end{aligned}$$

We note that the ratio $R_{\ell\ell}(b\bar{b})$ is bounded from above. The bound $R_{\ell\ell} = 10/26$ is reached [F3] for complete mixing ($r = 1$) and an $SU(3)$ -symmetric sea ($\kappa = 1/3$). We remark that the ratio $R_{\ell\ell}(b\bar{b})$ is independent of the details of the structure and fragmentation functions. In Table - 1 we present the values for the ratio r and $R_{\ell\ell}(b\bar{b})$ for various values of τ_B and the bag constant, $\mathcal{B}$. For all these values $R_{\ell\ell}(b\bar{b})$ turns out to be a significant number (≥ 0.12). Our best guess for the highest PETRA/PEP e^+e^- and the present $p\bar{p}$ collider energies is $R_{\ell\ell}(b\bar{b}) \simeq 0.2$, corresponding to $\tau_{B_s} \simeq 1.0 \times 10^{-12}$ sec, $\mathcal{B} \simeq 1.0$ and $\kappa \simeq 0.2$.

Before we estimate the absolute dilepton rates we would like to point out the signatures which are characteristic of the $B_s^0 - \bar{B}_s^0$ mixing. We recall that in the fragmentation process

$$b \rightarrow (b\bar{s}) + s \xrightarrow{\quad} X \tag{21}$$

there is always an s -quark left-over which will fragment giving K -mesons and Λ -hyperons. It is an experimental fact that the ratio $\frac{s \rightarrow \Lambda}{s \rightarrow K}$ is increasing with $\sqrt{s}$ in e^+e^- annihilation, with the ratio Λ/K_s^0 reaching ~ 0.5 for $p_\Lambda > 0.5$ GeV⁽¹²⁾. Thus, we expect that at both the PETRA/PEP and the $p\bar{p}$ collider energies, a not too insignificant number of the same sign dilepton events due to weak mixings should be accompanied by Λ 's. Further, if in addition the meson to baryon production cross-section is large [F4] i.e. if

$$\sigma(P\bar{P}_{e^+e^-} \rightarrow B_S^0 \bar{B}_S^0 X) / \sigma(P\bar{P}_{e^+e^-} \rightarrow \Lambda_b^0 \bar{B}_S^0 X) \gg 1$$

then the $B_S^0 - \bar{B}_S^0$ mixing would induce an additional correlation: one would then have

$$P\bar{P}_{e^+e^-} \rightarrow B_S^0 \bar{B}_S^0 \rightarrow \begin{matrix} l^+ l^+ \Lambda^0 X \\ l^- l^- \bar{\Lambda}^0 X \end{matrix} \quad (22)$$

giving rise to final states in which the dilepton charge is correlated with the baryon number of $\Lambda^0/\bar{\Lambda}^0$. Clearly, since in (22) the $\Lambda^0/\bar{\Lambda}^0$ is a fragment of the left-over s-quark the $l\Lambda^0/\bar{l}\bar{\Lambda}^0$ invariant mass is not bounded by m_B [F5].

The other point concerns the fact that the hadronic matter x in (22) will contain dominantly the charm $F^\pm$ mesons coming from the decays of the B_S meson, which can either be detected in a vertex detector or tagged via their observed decay modes, for example $F^\pm \rightarrow \phi \pi^\pm$. Thus, the same-sign dilepton events with large- p_T leptons [F6] almost back to back in the transverse plane and accompanied with $F^\pm$ mesons provide an ideal set-up to tag the B_S^0 mesons and hence measure their life-time, $\tau_{B_S^0}$.

Next, we consider the event rates in e^+e^- and $p\bar{p}$ collisions and estimate various backgrounds. The observed cross-section in e^+e^- annihilation can be estimated as follows ($\sigma_{had} \equiv \sigma(e^+e^- \rightarrow \text{hadron})$ and $\sigma(b\bar{b} \rightarrow \ell\ell)$ is the total dimuon cross-section from $(e^+e^- \rightarrow b\bar{b})$:

$$\begin{aligned} \frac{\sigma(e^+e^- \rightarrow l^+l^+ + l^-l^-)}{\sigma_{had.}} &= \frac{R^{\ell\ell}(b\bar{b})}{1 + R^{\ell\ell}(b\bar{b})} \cdot \frac{\sigma(b\bar{b} \rightarrow \ell\ell)}{\sigma_{had.}} \\ &= \frac{R^{\ell\ell}(b\bar{b})}{1 + R^{\ell\ell}(b\bar{b})} \cdot \frac{\sigma(b\bar{b})}{\sigma_{had.}} (BR)^2 \approx 2.7 \times 10^{-5} \\ &\quad \text{(for } \mu^+\mu^+ + \mu^-\mu^-) \end{aligned} \quad (23)$$

The number calculated in (23) assumes an optimistic dimuon detection efficiency, $\epsilon \simeq 10\%$ so as to remove the cascade leptons. We remark that the non-observation of energetic same-sign di-muons in e^+e^- experiments is consistent with expectations.

The situation at the $p\bar{p}$ collider, however, is very different. This stems from the fact that in $p\bar{p}$ collisions the large- p_T production of $b\bar{b}$ pairs is expected to be abundant. In Table II we show the cross-sections from the processes

$$\begin{aligned} G + G &\rightarrow Q + \bar{Q} \\ q + \bar{q} &\rightarrow Q + \bar{Q} \end{aligned} \quad (24)$$

for $Q = c, b$ and t -quarks for various $p_T(Q)$ cut-offs. The numbers correspond to using the Glück-Hoffman-Reya structure-functions⁽¹³⁾, $\Lambda = 0.3$, $M_t = 40$ GeV and a pseudo-rapidity cut-off $|\eta| = 2.0$. It is clear that the cross-section $\sigma(p\bar{p} \rightarrow b\bar{b})$ with a usual jet-trigger $E_T^{\text{jet}} \geq \sim 10$ GeV is in excess of $1 \mu\text{b}$. We observe that this cross-section is at least 4 orders of magnitude bigger than the typical x-section $\sigma(e^+e^- \rightarrow b\bar{b})$ at PEP and PETRA. Thus, the dimuon cross-section from $b\bar{b}$ and $c\bar{c}$ pair production is observable in $p\bar{p}$ collisions and this point is well appreciated in the literature⁽¹⁴⁾.

We have compared our theoretical calculation with the dimuon data from the UA1 collaboration as reported in Ref. 15. The detailed theoretical distributions together with some questions related to the heavy flavour production in $p\bar{p}$ collisions will be published elsewhere⁽¹⁶⁾. We present here the relevant numbers from this analysis. The calculations make use of the Peterson et al. fragmentation functions⁽¹⁷⁾ fitted to the latest e^+e^- data⁽¹⁸⁾. In Table 3 we present the expected number of dimuon events taking into account the UA1-trigger, namely

$$|\eta_\mu^{\text{Trigger}}| \leq 1.3, \quad |\eta_{2\mu}| \leq 2.0, \quad p_T^\mu > 5.0 \text{ GeV}. \quad (25)$$

It is clear from Table 3 that with the trigger (25) the dimuon events at the $p\bar{p}$ collider are dominated by the process $p\bar{p} \rightarrow b\bar{b} \rightarrow \ell\ell + x$. This conclusion is in agreement with earlier estimates of the dimuon yield at the collider⁽¹⁴⁾. Based on our analysis we find that the total dimuon cross-section has the value (with the trigger (25)).

$$\sigma(p\bar{p} \rightarrow \mu\mu X) \simeq 0.24 \text{ nb}$$

This yields about 12 events for an effective luminosity $\mathcal{L} \cdot \epsilon \simeq 50 \text{ nb}^{-1}$, where ϵ is the dimuon detection efficiency. This number is in reasonable agreement with the UA1 data consisting of 10 dimuon events.

In the rest of this paper we concentrate on the same - sign dimuons seen in the UA1-detector. We recall that the characteristic features of the [F7] observed same sign dimuon events are as follows:

- (i) p_T^μ is large for both the muons
- (ii) the μ 's are almost back to back in the azimuth
- (iii) the events are remarkably quite (i.e. accompanied with small jet activity), and
- (iv) the final state contains $\mu^+ \mu^+ \Lambda^0, \mu^- \mu^- \bar{\Lambda}^0$ among other particles.

The features (i) and (iii) make the cascade process (i.e. normal b decays without mixing)

$$p\bar{p} \rightarrow b\bar{b} \begin{array}{l} \searrow \bar{c} \rightarrow l^- \\ \swarrow l^- \end{array} + c.c. \quad (26)$$

a somewhat unlikely explanation of the UA1 same-sign dimuon events. We estimate the cross-section from the cascade process (26) to be ~ 1 Pb for $p_T^\mu > 10$ GeV, yielding only ~ 0.05 event. But more importantly the topology of the same-sign dimuon events from (25) should be dominantly such that one of the muons must be accompanied with a lot of hadronic (jet) energy, since the primary decay of one of the bottom quarks is purely non-leptonic. This is contrary to the data.

The features (ii) and (iii) render the mechanisms $t\bar{t} \rightarrow e^+ e^+ + x$ and $W^+ (W^-) \rightarrow t\bar{b} (\bar{t}b) \rightarrow e^+ e^+ (e^- e^-) + x$ improbable. Moreover, the expected cross sections for the $t\bar{t}$ and $W^+ (W^-)$ production are very small. There is, however, a potential source of multi-leptons (and hence same sign dileptons) at the $p\bar{p}$ collider from gluon fragmentation into a $c\bar{c}$ pair, leading to, for example, double charm pair production:

$$p\bar{p} \rightarrow G G + \dots \begin{array}{l} \searrow c \bar{c} \rightarrow l^+ \dots \\ \swarrow c \bar{c} \rightarrow l^+ \dots \end{array} \quad (27)$$

The p_T^l -spectrum on the other hand of such leptons is expected to be very soft and they will not survive the UA1 p_T^μ trigger. In addition, such dimuon events will have the usual associated jet activity, thereby, failing to reproduce the feature (iii) of the same sign dimuon data. We remark in passing that there is very little evidence of any sizeable $c\bar{c}$ component in the fragmentation of jets (mainly quarks) in $e^+ e^-$ data⁽¹⁹⁾. The production of $c\bar{c}$ in the fragmentation of more energetic gluon jets at the collider

may turn out to be somewhat larger than in the PETRA/PEP jets. The perturbative estimate for $GG \rightarrow c\bar{c} \ c\bar{c}$ is proportional to $O(\alpha_s^4)$ and hence entirely negligible.

Finally, another possible source of the same-sign dimuons could be the presence of a non-diagonal neutral current component in the b-quark decays giving rise to final states

$$\begin{array}{l}
 p\bar{p} \rightarrow b\bar{b} \\
 \quad \swarrow \quad \searrow \\
 \quad \quad \ell^+ \chi \\
 \quad \quad (d,s) \ell^+ \ell^-
 \end{array} \tag{28}$$

in which one of the leptons is removed by the μ -trigger requirements. However, the present upper limit on the branching ratio $\frac{b \rightarrow \ell^+ \ell^- \chi}{b \rightarrow all} < 0.6\%$ rules out (28) as a viable mechanism.

Thus, whereas the dimuon yield observed by the UA1 group is in reasonable agreement with the usual perturbative QCD estimates of a $Q\bar{Q}$ and $W^+(W^-)$ production and semi-leptonic decays, the same sign dimuons have characteristic features and rates which cannot easily be accommodated in a scenario in which the $B_s^0 - \bar{B}_s^0$ mixing is entirely neglected.

We have argued that both the relative same-sign to opposite-sign dimuon ratio $R_{\ell\ell}(b\bar{b}) \simeq 0.2$ expected from the $B_s^0 - \bar{B}_s^0$ mixing and the total dimuon rate are in reasonable agreement with the UA1 data. The V-A favoured p_T^μ - spectrum of the $b \rightarrow \mu \chi$ decays, the UA1 - trigger requirements and the harder $b \rightarrow B$ fragmentation function as measured in e^+e^- experiments lead to a reduced associated jet-activity. In addition the characteristic signatures of the $B_s^0 - \bar{B}_s^0$ mixing leading to $p\bar{p} \rightarrow \ell^+ \ell^+ \Lambda^0 (\ell^- \ell^- \bar{\Lambda}^0) + \dots$ strengthen the case for weak mixings. It would be extremely interesting to see if high statistics $p\bar{p}$ and e^+e^- data confirm the present conclusions.

We would like to thank our colleagues at CERN especially Karsten Eggert, John Ellis, Bob van Eijk, Martyn Corden and Carlo Rubbia for numerous helpful discussions. We also thank John Ellis for reading the manuscript.

FOOTNOTES

- [F1] We neglect CP-violation effects in the $B_S^0 - \bar{B}_S^0$ sector, which are expected to be very small.
- [F2] Here we are tacitly assuming that the semileptonic branching ratios for the B_d^0 , B_u^- and B_s^0 mesons are equal. Measurements of $BR(B_d^0, B_u^- \rightarrow \ell^\pm X)$ at CESR and the average branching ratio ($b \rightarrow \ell^\pm X$) measured at PETRA/PEP support this assumption (see, for example, ref. 2).
- [F3] We emphasize that this bound applies only to the primary leptons in the decay $b \rightarrow \ell + X$.
- [F4] This is in line with the measurement of meson/baryon yield in e^+e^- experiments.
- [F5] The correlation presented in Eq. (22) will of course be somewhat diluted by the processes involving a bottom baryon $\Lambda_b/\bar{\Lambda}_b$,

$$p\bar{p} \rightarrow \bar{\Lambda}_b B_s^0 \quad + c.c.$$

$$\begin{array}{c} \searrow \\ \bar{B}_s^0 \rightarrow \ell^+ \\ \swarrow \\ \ell^+ \bar{\Lambda}^0 X \end{array}$$

which, though itself a sign of weak mixing, has in the final states $\ell^+ \ell^+ \bar{\Lambda}^0$ and $\ell^- \ell^- \bar{\Lambda}^0$. However, in this case one has $m(\ell^+ \bar{\Lambda}^0) < m(\bar{\Lambda}_b)$. Presumably the production cross-section for the $\bar{\Lambda}_b B_s^0$ mode should be considerably lower than the $B\bar{B}$ meson pair production cross-section.

- [F6] In e^+e^- annihilation the dimuons will be almost back to back and the p_T^μ should be measured with respect to the jet axis.
- [F7] The UA1-data⁽¹⁵⁾ has three same-sign dimuon events out of a total of ten dimuons where one of them has a large energy jet associated with it.
- We concentrate here on the remaining 2 same sign dimuon events with
- $$(p_T^{\mu_1}, p_T^{\mu_2}) = (5.1 \pm 0.2, 7.3 \pm 0.5) \text{ GeV and } (10.4 \pm 1.1, 11.3 \pm 1.4) \text{ GeV}$$
- and small associated jet activity.

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TABLE CAPTIONS

- Table 1 The ratio $\Delta M/\Gamma$, $r = B_s^0 \rightarrow \ell^+ \nu \chi^- / B_s^0 \rightarrow \ell^- \bar{\nu} \chi^+$ and the same-sign to opposite sign dilepton ratio $R_{\ell\ell}(b\bar{b})$ as defined in Eq. (19) for the assumed values of the B_s^0 lifetime, the bag constant and the probability of $s\bar{s}$ pair excitation from the vacuum, χ
- Table 2 Inclusive heavy quark cross-sections $p\bar{p} \rightarrow Q + x$ from heavy quark pair production via the perturbative QCD mechanism of Eq. (24). The numbers are calculated for $\sqrt{s} = 540$ GeV and a pseudo-rapidity range $|\eta| \leq 2.0$. For details see text.
- Table 3 The dimuon cross-section estimated for the CERN $p\bar{p}$ collider with the UA1 trigger requirements and $p_T^\mu > 5$ GeV. For details see text.

Table 1

$\tau_{B_s} \times (10^{-12} \text{ sec.})$	1.1		1.4		1.7	
bag const., β	0.5	1.0	0.5	1.0	0.5	1.0
$\frac{\Delta M}{\Gamma}$	1.13	2.26	1.44	2.88	1.75	3.5
r	0.39	0.72	0.51	0.80	0.6	0.86
$R^{\ell\ell}(b\bar{b}) (\chi = 0.2)$	0.12	0.18	0.15	0.20	0.16	0.20
$R^{\ell\ell}(b\bar{b}) (\chi = 0.3)$	0.18	0.29	0.22	0.30	0.25	0.32

Table 2

	$p_T^Q = 5 \text{ GeV}$	8 GeV	10 GeV
$p\bar{p} \rightarrow c + x$	$5.9 \mu\text{b}$	$1.05 \mu\text{b}$	451 nb
$p\bar{p} \rightarrow b + x$	$1.95 \mu\text{b}$	$0.7 \mu\text{b}$	310 nb
$p\bar{p} \rightarrow t + x$	0.74 nb	0.71 nb	0.67 nb

Table 3

	$\mu^+ \mu^-$	$\mu^+ \mu^+ + \mu^- \mu^-$	$\Sigma \mu\mu$
$p\bar{p} \rightarrow c\bar{c} \rightarrow \ell\ell + x$	0.04 nb	-	0.04 nb
$p\bar{p} \rightarrow b\bar{b} \rightarrow \ell\ell + x$	0.15 nb	0.04 nb	0.19 nb
$p\bar{p} \rightarrow t\bar{t} \rightarrow \ell\ell + x$	$5.5 \times 10^{-3} \text{ nb}$	$2.5 \times 10^{-3} \text{ nb}$	$8 \times 10^{-3} \text{ nb}$