B^0-$\overline{B}^0$ MIXING

For a discussion of B^0-$\overline{B}^0$ mixing see the note on "B^0-$\overline{B}^0$ Mixing and *CP* Violation in *B* Decay" below.

χ_d

This B^0-$\overline{B}^0$ mixing parameter measures the probability (integrated over time) that a produced B^0 (or $\overline{B}^0$) decays as a $\overline{B}^0$ (or B^0), e.g. for inclusive lepton decays

$$\chi_d = \Gamma(B^0 \to \ell^- X \text{ (via } \overline{B}^0))/\Gamma(B^0 \to \ell^\pm X)$$
$$= \Gamma(\overline{B}^0 \to \ell^+ X \text{ (via } B^0))/\Gamma(\overline{B}^0 \to \ell^\pm X)$$

Where experiments have measured the parameter $r = \chi/(1-\chi)$, we have converted to χ. Mixing violates the $\Delta B \neq 2$ rule.

Note that the measurement of χ at energies higher than the $\Upsilon(4S)$ have not separated χ_d from χ_s where the subscripts indicate $B^0(\overline{b}d)$ or $B^0_s(\overline{b}s)$. They are listed in the B^0_s-$\overline{B}^0_s$ MIXING section.

The experiments at $\Upsilon(4S)$ make an assumption about the $B^0\overline{B}^0$ fraction and about the ratio of the $B^\pm$ and B^0 semileptonic branching ratios (usually that it equals one).

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
0.156±0.024 OUR AVERAGE					
0.16 ±0.04 ±0.04		[196] ALBRECHT	94	ARG	$e^+e^- \to \Upsilon(4S)$
0.149±0.023±0.022		[197] BARTELT	93	CLE2	$e^+e^- \to \Upsilon(4S)$
0.171±0.048		[198] ALBRECHT	92L	ARG	$e^+e^- \to \Upsilon(4S)$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.24 ±0.12		[199] ELSEN	90	JADE	e^+e^- 35–44 GeV
$0.158^{+0.052}_{-0.059}$		ARTUSO	89	CLEO	$e^+e^- \to \Upsilon(4S)$
0.17 ±0.05		[200] ALBRECHT	87I	ARG	$e^+e^- \to \Upsilon(4S)$
<0.19	90	[201] BEAN	87B	CLEO	$e^+e^- \to \Upsilon(4S)$
<0.27	90	[202] AVERY	84	CLEO	$e^+e^- \to \Upsilon(4S)$

[196] ALBRECHT 94 reports r=0.194 ± 0.062 ± 0.054. We convert to χ for comparison. Uses tagged events (lepton + pion from D^*).

[197] BARTELT 93 analysis performed using tagged events (lepton+pion from D^*). Using dilepton events they obtain $0.157 \pm 0.016^{+0.033}_{-0.028}$.

[198] ALBRECHT 92L is a combined measurement employing several lepton-based techniques. It uses all previous ARGUS data in addition to new data and therefore supersedes ALBRECHT 87I. A value of r = 20.6 ± 7.0% is directly measured. The value can be used to measure $x = \Delta M/\Gamma = 0.72 \pm 0.15$ for the B_d meson. Assumes $f_{+-}/f_0 = 1.0 \pm 0.05$ and uses $\tau_{B^\pm}/\tau_{B^0} = (0.95 \pm 0.14)\ (f_{+-}/f_0)$.

[199] These experiments see a combination of B_s and B_d mesons.

[200] ALBRECHT 87I is inclusive measurement with like-sign dileptons, with tagged B decays plus leptons, and one fully reconstructed event. Measures r=0.21 ± 0.08. We convert to χ for comparison. Superseded by ALBRECHT 92L.

[201] BEAN 87B measured $r <$ 0.24; we converted to χ.

[202] Same-sign dilepton events. Limit assumes semileptonic BR for B^+ and B^0 equal. If $B^0/B^\pm$ ratio <0.58, no limit exists. The limit was corrected in BEAN 87B from $r <$ 0.30 to $r <$ 0.37. We converted this limit to χ.

$\Delta m_{B^0} = m_{B^0_H} - m_{B^0_L}$

Δm_{B^0} is a measure of the B^0-$\overline{B}^0$ oscillation frequency in time-dependent mixing experiments.

VALUE (10^{12} $\hbar$ s^{-1})	DOCUMENT ID		TECN	COMMENT
0.51 ±0.06 OUR AVERAGE				
0.508±0.075±0.025	[203] AKERS	94C	OPAL	$e^+e^- \to Z$
$0.50\ ^{+0.07}_{-0.06}\ ^{+0.11}_{-0.10}$	[204] BUSKULIC	94B	ALEP	$e^+e^- \to Z$
$0.52\ ^{+0.10}_{-0.11}\ ^{+0.04}_{-0.03}$	[205] BUSKULIC	93K	ALEP	$e^+e^- \to Z$

[203] AKERS 94C observes the time dependence of B^0-$\overline{B}^0$ mixing using $D^{*\pm}\ell^\mp$ events and jet charge.

[204] BUSKULIC 94B observes the time dependence of B^0-$\overline{B}^0$ mixing using dileptons.

[205] BUSKULIC 93K observes the time dependence of B^0-$\overline{B}^0$ mixing using D^{*+} lepton correlations.

$x_d = \Delta m_{B^0}/\Gamma_{B^0}$

This section combines results from the previous two sections.

Time integrated mixing measurements of χ determine this quantity directly via

$$\frac{\Delta m_{B^0}}{\Gamma_{B^0}} = \left(\frac{\chi}{0.5-\chi}\right)^{1/2}$$

while time-dependent mixing measurements determine $\Delta m_{B^0} = m_{B^0_H} - m_{B^0_L}$ which are combined with τ_{B^0} to give

$$\frac{\Delta m_{B^0}}{\Gamma_{B^0}} = \frac{(m_{B^0_H} - m_{B^0_L})\ \tau_{B^0}}{\hbar}\ .$$

The averaging takes into account the common systematic errors on the LEP experiments due to τ_{B^0}.

VALUE	DOCUMENT ID		TECN	COMMENT
0.71±0.06 OUR AVERAGE				
0.76±0.11±0.06	[206] AKERS	94C	OPAL	$e^+e^- \to Z$
0.69±0.18	[207] ALBRECHT	94	ARG	$e^+e^- \to \Upsilon(4S)$
$0.75^{+0.20}_{-0.18}\pm0.06$	[206] BUSKULIC	94B	ALEP	$e^+e^- \to Z$
0.65±0.10	[207] BARTELT	93	CLE2	$e^+e^- \to \Upsilon(4S)$
$0.78^{+0.16}_{-0.17}\pm0.06$	[206] BUSKULIC	93K	ALEP	$e^+e^- \to Z$
0.72±0.15	[207] ALBRECHT	92L	ARG	$e^+e^- \to \Upsilon(4S)$

[206] Value is their Δm_{B^0} measurement combined with τ_{B^0} = (1.50 ± 0.11) ps, the average from this edition. The systematic error on τ_B and is common to experiments bearing this footnote. The averaging takes this into account.

[207] Derived from time-integrated mixing parameter χ.

B^0–$\overline{B}^0$ MIXING AND *CP* VIOLATION IN *B* DECAY

(by H. Quinn, SLAC)

The neutral B meson system is like the neutral kaon system, in that two CP-conjugate states exist. The mass eigenstates are mixtures of these states, the mixing being due to box diagrams, shown in Figure 1. The two mass eigenstates can be written

$$|B_L\rangle = p|B_0\rangle + q|\overline{B}^0\rangle\ ,$$
$$|B_H\rangle = p|B_0\rangle - q|\overline{B}^0\rangle\ . \tag{1}$$

Here H and L stand for Heavy and Light, respectively.

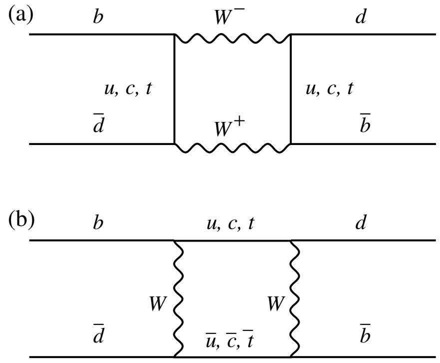

Figure 1: Mixing Diagrams.

Whereas in the kaon case the lifetimes of the two eigenstates are significantly different and the difference in masses between them is small, in the B system it is the mass differences that dominate the physics, and the two states have nearly equal predicted widths (and thus lifetimes).

$$\Gamma = (\Gamma_H + \Gamma_L)/2\ ,\ \Delta\Gamma = \Gamma_H - \Gamma_L\ . \tag{2}$$

The difference between the widths of the two eigenstates is produced by the contributions from channels to which both B^0 and $\overline{B}^0$ can decay. These have branching ratios of $\mathcal{O}(10^{-3})$ [1]. Furthermore there are contributions of both signs to the difference, so there is no reason that the net effect should be much larger than the individual terms. Conservatively, one expects $\Delta\Gamma/\Gamma \leq 10^{-2}$. Experimentally no effect of a difference in lifetimes has been observed. In what follows, we neglect any effects from $\Delta\Gamma$, except where explicitly stated. We define also

$$M \equiv (M_H + M_L)/2\ ,\quad \Delta M \equiv M_H - M_L\ . \tag{3}$$