REPORT OF THE MIXING SUB-GROUP[*] OF THE δ WORKING GROUP (OTHER B PHYSICS)

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1. INTRODUCTION

1.1 Motivation

With the mixing parameter x defined as $\Delta m/\Gamma$ for neutral B mesons, the ratio of the mixing parameters for the B_d and B_s mesons is given by:

$$x_d/x_s = |V_{td}/V_{ts}|^2 \left(m_{\mathrm{B}_d}/m_{\mathrm{B}_s}\right) \left(\tau_{\mathrm{B}_d}/\tau_{\mathrm{B}_s}\right) \left(f^2_{\mathrm{B}_d} B_d / f^2_{\mathrm{B}_s} B_s\right). \tag{1}$$

The value of x_d is known to good precision[1] ($x_d = 0.665 \pm 0.088$), and the ratio of theoretical form factors $\left(f^2_{\mathrm{B}_d} B_d / f^2_{\mathrm{B}_s} B_s\right)$ should be calculated to 10% - 20% accuracy within next couple of years[2]. Therefore, a measurement of x_s can provide a precise measurement of the $|V_{td}/V_{ts}|$ ratio. This information, coupled with the measurements of $|V_{ub}|$ and $|V_{cb}|$ from CLEO[3], enables an independent determination of the CKM unitarity triangle through a measurement of its sides, rather than angles. Present estimates for quantities entering Eq. (1), predict a value of x_s within a range[4] of 10 to 30 within the Standard Model.

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1.2 Principles for evaluating B$_s$ *Mixing Proposals*

The Mixing Subgroup reviewed aspects of the B$_s$ mixing measurements, including:

- theoretical uncertainties[‡]
- CDF[1] and D0 prospects and proposed upgrades
- Super Fixed Target (SFT) prospects at the SSC[5]
- x_s reach of current e^+e^- experiments[6] operating at the Z^0.

The LEP results and prospects are discussed in the companion paper by X. Lou. The available statistics limit the x_s reach of the e^+e^- experiments to values less than 10. Only hadronic experiments have a reasonable chance to extend the x_s determination range up to 20. Therefore the rest of this summary is concerned with the hadronic experiments only.

A methodology for comparing various B$_s$ mixing experiments, developed by the group, is presented in the companion paper by T. Burnett[7]. The large expected value of x_s (> 10) requires an excellent time resolution to observe B$_s$ oscillations. Therefore only exclusive, fully reconstructed B$_s$ decay modes are suitable. We found the decay modes $\mathrm{B}_s \to \mathrm{D}_s 3\pi$ and $\mathrm{B}_s \to \mathrm{D}_s \pi$ with only charged particles in the final state to be the most attractive for the B$_s$ mixing determination at large values of x_s. They have a relatively large combined branching ratio[1] ($4.2 * 10^{-4}$), allow self tagging at $t > 0$, and have additional kinematic constraints to help improve the background rejection.

The number of events required to determine x_s was estimated using two methods. A first estimate (termed 'the BCD method') used a formula, taken from one of the BCD proposals[8], based on a requirement of 25 events in the 8th quarter of oscillations. A second estimate (termed 'the maximum likelihood method', or ML) required the σ for the x_s measurement as computed by the maximum likelihood method to be less than 0.20. In the case of perfect time resolution and a dilution factor of 1, this corresponds to at least 25 events observed. Monte Carlo simulations[7] indicate that in 90% of the cases the ML method would obtain a correct value of x_s with a σ_x of 0.20.

The formulas used by the BCD and ML methods for the required number of detected events ($= \varepsilon N_{\mathrm{prod}}$, where N_{prod} is the number of produced events and ε is the efficiency for detecting them) were:

$$N_{\mathrm{det}}^{\mathrm{BCD}}(x_s) = \frac{50 x_s}{\pi D^2} \cdot \exp\left[\frac{4\pi}{x_s} + ({x_s}^2 - 1)\frac{\sigma_t^2}{2}\right], \tag{2}$$

$$N_{\mathrm{det}}^{\mathrm{ML}} = \frac{1}{D^2 d_{time}^2 \sigma^2}, \tag{3}$$

or, for the choice of σ_x made above,

$$N_{\mathrm{det}}^{\mathrm{ML}} = \frac{25}{D^2 d_{time}^2}, \tag{4}$$

where D represents the total dilution factor excluding the effective dilution factor d_{time} due to time resolution[7]. Monte Carlo simulations indicate that the number of events given by the ML method should be sufficient for a first measurement of x_s, whereas the BCD method gives the number of events required for a precision measurement.

1.3 Comparison Table Contents

See Table I for a summary of our investigations for the individual experiments. The organization of Table I is described as follows:

- Rows 1 through 9 describe assumptions concerning expected luminosity, the $B\overline{B}$ cross section, selected B$_s$ decay modes, and $t = 0$ tagging.
- Rows 10 through 13 give the assumed efficiencies for geometrical acceptance, off-line reconstruction, triggering, and tagging for $t > 0$. The numbers were determined by Monte Carlo studies done previously[9,10].
- Row 14, the number of B$_s$'s reconstructed, is obtained from the number of B$_s$ produced in 10^7 seconds (Row 6) multiplied by the branching ratio (Row 8) and the overall efficiency (Row 21).
- Rows 15 and 16 describe the expected proper time resolution as determined by Monte Carlo studies.
- Rows 17 through 20 give various dilution factors. d_{mix} represents an inherent mistagging at $t = 0$ due to mixing of some of the b-quark hadrons recoiling against the B$_s$. It is averaged over expected fractions of b-quark hadrons. d_{tag} represents mistagging at $t = 0$ due to experimental misidentification of the tagging lepton, d_{bg} represents background in the reconstructed B$_s$ mass spectrum, and d_{time} represents the effective dilution due to finite time resolution[7]. d_{time} is a function of the expected x_s value. We quote numbers for $x_s = 5$, 10 and 20.
- Rows 21 and 22 give the total efficiency (= the product of the individual efficiencies) and the product of the dilution factors.
- Rows 23 and 24 give the numbers of events required to measure x_s, as determined by the two methods. They should be compared against the number of reconstructed B$_s$ per nominal year (10^7 seconds), given in row 14.
- Row 26 gives the maximum x_s and is determined from the proper time uncertainty alone using the formula[1] $x_s^{max} = (\pi/2)(\tau/\sigma_t)$.

3. CONCLUSIONS

The tables indicate that the several experiments proposing to measure x_s should be able to go to an x_s of at least 20 based on time resolution alone. The SFT experiment, with its excellent proper time resolution due to the precise measurement of the long B decay length with a silicon vertex detector, has the best x_s reach. However, studies remain to be done to determine whether or not there are sufficient statistics to measure large x_s.

In approximately a year's running with the Main Injector at full luminosity, upgraded CDF and D0 detectors should be able to accumulate enough events to determine $x_s \leq 20$. Thus, B$_s$ mixing measurements are feasible by the end of this century and hadronic collider

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experiments have a clear advantage with their large $B\overline{B}$ cross section. Many of the Monte Carlo inputs used in this summary should be verified by CDF during the forthcoming run in 1994. This will lead to an improved understanding of the statistics required and ultimate x_s reach of hadron collider experiments.

5. REFERENCES

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8. K. T. McDonald, "Maximum-Likelihood Analysis of *CP*-Violating Asymmetries," Princeton/HEP/92-04. See also BCD Collaboration, Expression of Interest for A Bottom Collider Detector at the SSC, May 25, 1990, p. 14-16.
9. "CDF SVX II Upgrade Proposal", CDF Note No. **1922** (1993)
10. R. Lipton, D0 Note No. **1905**.

Table I - Comparison of proposed B$_s$ Mixing Measurement Prospects at Hadron Accelerators

1	Experiment:	CDF - Mode 1	CDF - Mode 2 (C)	CDF - Mode 3 (C)	D0	SFT
2	Energy E_{cm} (TeV)	1.8	1.8	1.8	1.8	0.193
3	Luminosity L (10^{33} cm^{-2}s^{-1})	0.1	0.1	0.1	0.1	0.02 (D)
4	Cross section $\sigma_{b\bar{b}}$ (μb)	100	100	100	100	2 (E)
5	B_s^0 fraction	0.15	0.15	0.15	0.15	0.15
6	N_{prod} / 10^7 s	$3.0 * 10^{10}$	$3.0 * 10^{10}$	$3.0 * 10^{10}$	$3.0 * 10^{10}$	$1.2 * 10^8$
7	Mode to tag B_s^0	$B_s \to D_s 3\pi, D_s\pi$	$B_s \to$ *lepton* D_s	$B_s \to$ *lepton* ϕ	$B_s \to D_s 3\pi, D_s\pi$	$B_s \to D_s 3\pi$
8	B_s^0 branching ratio	$(4.2 \pm 0.7) * 10^{-4}$	$(3.8 \pm 0.5) * 10^{-3}$	$(8.9 \pm 2.0) * 10^{-3}$	$(4.2 \pm 0.7) * 10^{-4}$	$2.5 * 10^{-4}$
9	B (t=0) tag	e, μ	e, μ	e, μ	μ^+, μ^-	lepton
10	ε_{geom}	0.7	0.7	0.7	0.5	0.57
11	ε_{reco} (A)	$0.30 * \varepsilon_1^{rec}$	$0.37 * \varepsilon_2^{rec}$	$0.41 * \varepsilon_3^{rec}$	0.27	0.48
12	ε_{trig}	$1.63 * 10^{-3}$	$1.63 * 10^{-3}$	$1.63 * 10^{-3}$	$5.00 * 10^{-3}$	$0.8 * 10^{-2}$
13	ε_{tag}	1.0 (F)	0.039	0.039	0.6	1.0 (F)
14	Number of B_s^0 reconstructed	$4313 * \varepsilon_1^{rec}$	$1877 * \varepsilon_2^{rec}$	$4871 * \varepsilon_3^{rec}$	5103	66
15	a ($\sigma_t = a \oplus bt$) (G)	0.08	0.11	0.13	0.08	0.025
16	b ($\sigma_t = a \oplus bt$) (G)	0.036	0.10	0.15	0.0	0.0
17	d_{mix}	0.66	0.66	0.66	0.65	0.76
18	d_{tag}	0.80	0.80	0.80	0.6	0.90
19	d_{bg} (B)	–	–	–	–	–
20	d_{time} ($x_s = 5/10/20$)	0.88/0.69/0.26	0.45/0.16/0.02	0.31/0.085/0.0082	0.88/0.69/0.26	1.0/1.0/1.0
21	Total efficiency ε	$0.34 * 10^{-3} * \varepsilon_1^{rec}$	$0.0165 * 10^{-3} * \varepsilon_2^{rec}$	$0.0182 * 10^{-3} * \varepsilon_3^{rec}$	$0.41 * 10^{-3}$	$2.2 * 10^{-2}$
22	$d_{mix}d_{tag}d_{bg}d_{time}$ ($x_s = 5/10/20$)	0.46/0.36/0.14	0.24/0.084/0.011	0.16/0.044/0.004	0.34/0.27/0.10	0.68/0.68/0.68
23	N_{B_s} req. for $x_s = 10$ (BCD)	2755	5989	14101	5046	1233
24	N_{B_s} req. ($x_s = 5/10/20$) (ML)	$116/188/1.3K$	$442/3.5K/224K$	$933/12.4K/1.3M$	$212/345/2.4K$	53/53/53
25	σ_x for N_{B_s} (ML)	0.20	0.20	0.20	0.20	0.20
26	Maximum x_s	20	11	8	20	63

Notes: (A) $\varepsilon_{1,2,3}^{rec}$ are event reconstruction efficiencies to be determined using the data. (B): Background estimates to be determined from the data; d_{bg} taken as 1.0. (C): Estimates are for single lepton data; up to x2 signal available from dilepton data. (D) 10^7 interactions per second. (E): $A^{0.27}$ enhancement for Silcon target. (F): ε_{tag} is included in ε_{trig}. (G) t measured in units of proper time.