TWO TOPICS IN PARTICLE-ANTIPARTICLE MIXING

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1 Introduction

This paper discusses two experimental issues in the study of particle antiparticle mixing. We propose a new method to extract the ratio $|V_{td}/V_{ts}|^2$ from a measurement of $\Delta \Gamma/\Gamma$ for the $B_s$ meson. This method is experimentally more sensitive than the conventional method for large values of $|V_{ts}|$ but depends on the accuracy of parton level calculations. We then briefly discuss the implications of large CP violation and final state interactions (FSI) in the experimental search for $D^0 - \bar{D}^0$ mixing.

2 A New Method for Determining $|V_{td}/V_{ts}|^2$.

The measurement of the mixing parameter $x_s = \Delta m_s/\Gamma$ for the $B_s$ meson is one of the goals of high energy collider experiments and experiments planned for the facilities of the future. A measurement of $x_s$ combined with a determination of $x_d$ the corresponding quantity for the $B_d$ meson allows the determination of the ratio of the KM matrix elements $|V_{td}|^2/|V_{ts}|^2$ from the ratio

$$x_s = \frac{\frac{m_B}{m_{\bar{B}}}(\frac{B}{B^*}) \tau_s}{\frac{m_B}{m_{\bar{B}}}(\frac{B}{B^*}) \tau_d} \frac{|V_{ts}|^2}{|V_{td}|^2}$$

The factor which multiplies the ratio of KM matrix elements is unity up to $SU(3)$ breaking effects and has been estimated to be of order 1.3 [1]. Since time integrated measurements of $B_s$ mixing is insensitive to $x_s$ when mixing is maximal, one must make time dependent measurements in order to extract this parameter. A severe experimental difficulty is the rapid oscillation rate of the $B_s$ meson, as recent experimental limits indicate that $x_s > 8\%$ and theoretical fits to the Standard Model parameters suggest that $x_s$ lies in the range 10 – 40.

It should be noted that there is another parameter of the $B_s$ meson which can also be measured, this is $\Delta \Gamma/\Gamma$, the difference between the widths of the two $B_s$ eigenstates. For $|V_{ts}| \sim 0.043$ this could lead to a value of $\Delta \Gamma/\Gamma$ of order 10 – 20% which is measurable at high energy experiments or asymmetric B factories. In parton calculations

$$\Delta \Gamma = -\frac{G_F^2 f_B^2 m_B m_{\bar{B}}}{4\pi} \lambda_s^2 \left[ 1 + \frac{4}{3} \frac{\lambda_u m_u}{m_t} + O(m_c/m_t) \right]$$

Comparing to the dispersive term, this gives

$$\Delta \Gamma_{B_s} / \Delta m_{B_s} \approx -\frac{3}{2} \frac{m_B}{m_t} \left( \frac{\Delta \Gamma(B_s)}{\eta_{QCD}^B} \right) \frac{\Delta M(B_s)}{\eta_{QCD}^B}$$

where $m_u, m_t$ are the masses of the b and t quark respectively and terms of order $m_c^2/m_t^2, m_b^2/m_t^2$ are neglected. The last factor in the above expression, the ratio of QCD corrections for $\Delta \Gamma$ and $\Delta M_s$ is expected to be of order unity. All of the above factors in $\Delta \Gamma$ have a common mass dependence of $m_s^2$ in the leading term. From equations (1) and (3), the ratio $x_s/x_d$ is then given by

$$\frac{\Delta \Gamma_{B_s}}{\Delta m_{B_s}} = \frac{-3}{2} \frac{m_B}{m_t} \left( \frac{m_B \eta_{QCD}^B}{\eta_{QCD}^B} \right) \frac{\Delta M(B_s)}{\eta_{QCD}^B} \frac{|V_{ts}|^2}{|V_{td}|^2}$$

We have assumed that the lifetimes of the $B_d$ and $B_s$ mesons will have been measured to sufficient precision to extract this ratio. The above expression assumes unitarity since the leading term which enters in $\Delta \Gamma$ is

$$\lambda_u^2 + \lambda_c^2 + 2\lambda_u \lambda_c$$

which is expressed as

$$(\lambda_c + \lambda_u)^2 = (\lambda_t)^2$$

via unitarity of the KM matrix. In fact, all determinations of $|V_{ts}|$ which depend on virtual t quarks necessarily rely on the assumed unitarity of the $3 \times 3$ KM matrix. The only way to obtain values of $|V_{ts}|$ free from this assumption is through direct on-shell measurements of t decays.

Several authors have pointed out that the quantity $\Delta \Gamma(B_s)$ may be large since there are intermediate final states such as $B_s \rightarrow D_s^{(*)+} D_s^{(*)-}$ accessible to both $B_s$ and $B_s$ which have appreciable branching states. The calculation of Aleksan, Le Yaouanc, Oliver, Pene, and Raynal shows that the parton model estimate and the calculation using exclusive final states agree to within an accuracy of 30%. Given the large experimental uncertainties already present in the determination of the ratio $|V_{ts}|^2/|V_{td}|^2$, this is not yet a serious limitation.

In order to measure $\Delta \Gamma/\Gamma$, one must determine the lifetimes of two samples of events. One possibility is to use the large samples of $B_s \rightarrow \psi(3S) K^*$ events. This first sample may be dominated by events in a single CP eigenstate as is the case for $B_d \rightarrow \psi K^*$ which can be verified experimentally by measuring the polarization in this decay. The latter sample of semileptonic decays will be an incoherent mixture of both CP eigenstates. The measured lifetime difference will be $\Delta \Gamma/\Gamma^2$, which can then be used to constrain $|V_{ts}|^2/|V_{td}|^2$. Another possibility is to obtain $\Delta \Gamma$ by fitting the lifetime
distribution of a sample of $\bar{B}_s \rightarrow D_s^{(*)} + \ell^- \nu$ events to the sum of two exponential distributions and allowing for the oscillatory term.

The sensitivity of the two methods can be roughly compared as follows. The ALEPH lower limit on $x_s$ (8.4) corresponds to the lower limit $\Delta \Gamma / \Gamma > 0.033$ (3.3%). A measurement of a 7% lifetime difference corresponds to a central value of $x_s = 15$ for a time dependent oscillation study. For large values of $V_{ts}$, the method using $\Delta \Gamma$ eventually becomes more sensitive. Good control of systematic effects from the boost correction in $\bar{B}_s \rightarrow D_s^{(*)} + \ell^- \nu$ and the lifetime of the background sample are required. Feasibility studies of the technique introduced here have begun at the CDF experiment.\[1\]

3 Experimental Search for $D^0 - \bar{D}^0$ Mixing

As was recently noted by Blaylock, Seiden, and Nir\[7\] due to final state interaction (FSI) a term proportional to $\Delta M \ t e^{-\Gamma t}$, which was previously neglected, may appear in the rate of wrong sign $D$ decays (when combining samples of $D^0$ and $\bar{D}^0$ mesons) even in the absence of CP violation. Moreover, in some extensions of Standard Model which have large values of both $\Delta M$ and significant CP violation\[13\], a similar term may arise. Blaylock et al. have suggested that a value of $\Delta M$ larger than the present experimental limit can be accomodated if one of these previously neglected terms destructively interferes with the other time dependent terms which arise from mixing (proportional to $t^2 e^{-\Gamma t}$) and from doubly Cabibbo suppressed decays (DCSD) (proportional to $e^{-\Gamma t}$). They suggest that this may invalidate the use of existing limits from time dependent mixing studies at fixed target experiments\[4\] to constrain extensions of the Standard Model.

The conclusion of recent work done in collaboration with S. Pakvasa\[17\] is that, at the present level of sensitivity and with reasonable (though model dependent) values for the phase difference $\delta$, the $\Delta M \ t$ term which arises from FSI could change the observed event yield for experiments which study the time dependence of mixing by at most 10%. This is not yet a significant systematic experimental limitation. The contribution from the corresponding term proportional to $\Delta M \ t$ due to CP violation which arises in extensions of Standard Model is highly suppressed. This term is not observable at the present level of experimental sensitivity. However, as emphasized by Liu\[10\] and by Wolfenstein\[14\], this term should not be neglected as experimental examination of the $D^0(t) - \bar{D}^0(t)$ distribution may allow more sensitive searches for $D^0 - \bar{D}^0$ mixing in the future if the CP violating phase is large.

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