B_d MIXING AND PROSPECTS FOR B_s MIXING AT DØ

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ABSTRACT

Measurement of the B_s oscillation frequency via B_s mixing analyses provides a powerful constraint on the CKM matrix elements. The study of B_d oscillations is an important step towards B_s mixing and a preliminary measurement of Δm_d has been made with ~ 250 pb^-1 of data collected with the upgraded Run II DØ detector. Different flavor tagging algorithms have been developed and are being optimized for use on a large set of B_s mesons that have been reconstructed in different semileptonic decay modes.

1 Introduction

First observed in the B_d^0 – B_d^0 meson system at ARGUS, the neutral B meson transition from the particle to anti-particle state, and vice versa, occurs through a second order weak transition or “box diagram”. The frequency of the oscillation is proportional to the small difference in mass between the two eigenstates, Δm, and for the B_d^0 – B_d^0 system can be translated into a measurement of the CKM element |V_{td}|. |V_{td}| can be used to constrain the unitarity triangle and thereby yield information on the CP violating phase [1]. Δm_d has been precisely measured (the world average is Δm_d = 0.502 ± 0.007 ps^{-1} [2]) but large theoretical uncertainties dominate the extraction of |V_{td}| from Δm_d. This problem can be reduced if the
\(B^0_s\) mass difference, \(\Delta m_s\), is also measured. \(|V_{td}|\) can then be extracted with better precision from the ratio:

\[
\frac{\Delta m_s}{\Delta m_d} = \frac{m(B^0_s)}{m(B^0_d)} \xi^2 |\frac{V_{ts}}{V_{td}}|^2
\]

where \(\xi\) is estimated from Lattice QCD calculations to be \(1.15^{+0.12}_{-0.00}\). The above has motivated many experiments to search for \(B^0_s\) oscillations and though a statistically significant signal hasn’t been observed yet, a lower limit (\(\Delta m_s > 14.4\) ps\(^{-1}\) at 95\% C.L.) has been set. Since this current limit indicates that the \(B^0_s\) oscillations are at least 30 times faster than the \(B^0_d\) oscillations, a \(B^0_s\) mixing measurement is experimentally very challenging.

2 Experimental considerations

The DØ experiment at the Fermilab Tevatron, a \(p\bar{p}\) collider at 1.96 TeV center of mass energy, is well equipped to search for \(B^0_s\) oscillations. The large muon acceptance and forward tracking coverage of the DØ detector (pseudorapidity coverage of \(|\eta| < 2.0\) for the muon, \(|\eta| < 1.7\) for the tracking and \(|\eta| < 3.0\) for the silicon sub-detectors), along with a robust muon trigger are highly effective in exploiting the large \(b\bar{b}\) cross-section resulting in some of the largest semileptonic \(B^0_s\) yields. Fig. 1 shows the yield for the decay \(B^0_s \rightarrow D^- \mu^+ X (D^- \rightarrow \phi\pi^-)\) in \(\sim 250\) pb\(^{-1}\) of data. The decay \(B^0_s \rightarrow D^- \mu^+ X (D^- \rightarrow K^{*0}K^-)\) has also been reconstructed and is expected to contribute significantly to the total \(B^0_s\) yield. Other decays including hadronic \(B^0_s\) decays are being studied as well.

![Figure 1: \(B^0_s \rightarrow D^- \mu^+ X (D^- \rightarrow \phi\pi^-)\) yield.](image)

1Conjugate modes are implied throughout the paper
Other elements essential to a mixing analysis are given by the expression for the average statistical significance:

\[
\text{Significance}(\Delta m_s, \sigma_t) = \sqrt{\frac{S\epsilon D^2}{2}} \sqrt{\frac{S}{S + B}} e^{- (\Delta m_s \sigma_t)^2/2}
\]  

(2)

where \( S \) is the number of signal events, \( \epsilon D^2 \) is a measure of the effectiveness of a flavor tagger (\( \epsilon \) is the tagging efficiency while \( D \) is the “Dilution”), \( B \) is the number of background events and \( \sigma_t \) is the proper time resolution.

As indicated above, tagging the meson flavor (\( B^0_s \) or \( \bar{B}^0_s \)) at decay time (final-state tagging) and at production time (initial-state tagging) are crucial. For the semileptonic modes used for mixing studies at DØ the final state particles provide the decay-time tag. For initial-state tagging, different techniques are being studied and optimized by doing measurements of \( \Delta m_d \). Three tagging algorithms have been developed so far: opposite-side muon tagging, opposite-side jet charge tagging, and same-side (soft-pion) tagging.

The muon tagger relies on identifying the flavor of the other B meson in the event using the sign of the muon it decayed to - a negative muon corresponds to a \( b \) quark, and vice-versa. For the decay used for \( B^0_d \) mixing studies - \( B^0_d \rightarrow D^{*-} \mu X \) where \( D^{*-} \rightarrow \bar{D}^0 \pi^- \) and \( \bar{D}^0 \rightarrow K^+ \pi^- \) - both muons having the same sign would indicate that one B hadron had oscillated while opposite signs would indicate that neither (or both) had oscillated. Fig.2 shows the measured asymmetry between the non-oscillated and oscillated mesons as a function of the visible proper decay length (VPDL). The fit to the asymmetry gives \( \Delta m_d = 0.506 \pm 0.055 \pm 0.049 \) ps\(^{-1}\) with an efficiency of 4.8 \( \pm \) 0.2 \% and \( D = 46.0 \pm 4.2 \) \%.

![Figure 2: The asymmetry between the non-oscillated and oscillated mesons as a function of the visible proper decay length.](image.png)

The opposite-side jet charge tagging algorithm calculates a \( p_T \)-weighted average charge of tracks: \( \text{jetQ} \equiv \frac{\sum_p q_i}{\sum_p p_T} \). A \(|\text{jetQ}| < 0 \) value corresponds to a \( b \)
quark for the B meson on the opposite side, and vice-versa. The same-side pion tagging algorithm makes use of the fact that the charge of the fragmentation pion correlates with the flavor of the reconstructed B meson. A positive pion corresponds to a \( \bar{b} \) quark (i.e. \( B^0_d \)) if the reconstructed \( B \) meson is neutral, but to a \( b \) quark (i.e. \( B^- \)) if the reconstructed \( B \) meson is charged, and vice versa. Oscillations have been seen using both the opposite-side jet-charge and the same-side pion tags, and work is ongoing to compute systematics errors and optimize performance. Lastly, since the significance scales as \( e^{-\left(\Delta m_s \sigma t\right)^2/2} \), for large values of \( \Delta m_s \), a precise measurement of the proper decay time is crucial. Efforts are ongoing in this direction and we hope to have preliminary \( \Delta m_s \) results soon.

3 Conclusions

A preliminary measurement of \( \Delta m_d \) has been made with the upgraded DØ detector. The opposite-side soft muon tagger was used to obtain \( \Delta m_d = 0.506 \pm 0.055 \pm 0.049 \) ps\(^{-1} \). This measurement, along with the development and optimization of other tagging algorithms, and the reconstruction of different \( B_s \to D_{s}^{\mp} \mu^{\pm}X \) decay modes, is an important step towards a \( B_s \) mixing measurement.

References


3. O.Schneider, “\( B^0 - \bar{B}^0 \) mixing,” arXiv:hep-ex/0012010.