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B_d MIXING AND PROSPECTS FOR B_s MIXING AT DØ

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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 preliminary measurements of Δm_d have 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.

Keywords: B_s Mixing; B_d Mixing; DØ.

1. Introduction

First observed in the $B_d^0 - \bar{B}_d^0$ meson system at ARGUS[1], 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 $B_d^0 - \bar{B}_d^0$ 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[2]. Δm_d has been precisely measured (the world average is $\Delta m_d = 0.502 \pm 0.007$ ps^{-1})[3] but large theoretical uncertainties dominate the extraction of $|V_{td}|$ from Δm_d. This problem can be reduced if the B_s^0 mass difference, Δm_s, is also measured. $|V_{td}|$ can then be extracted with better precision from the ratio:

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m(B_s^0)}{m(B_d^0)} \xi^2 \left| \frac{V_{ts}}{V_{td}} \right|^2 \tag{1}$$

where ξ is estimated from Lattice QCD calculations to be $1.15^{+0.12}_{-0.00}$ (Ref. 3). The above has motivated many experiments to search for B_s^0 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_s^0 oscillations are at least 30 times faster than the B_d^0 oscillations, a B_s^0 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_s^0 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_s^0 yields. Fig. 1 shows the yield for the decay $B_s^0 \rightarrow D_s^- \mu^+ X (D_s^- \rightarrow \phi\pi^-)$ [a] in $\sim$250 pb^{-1} of data.

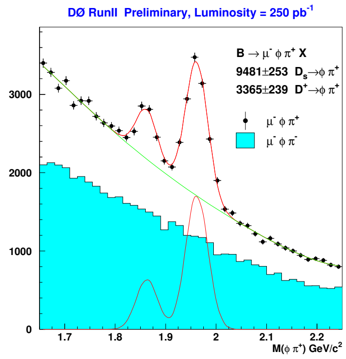

Fig. 1. $B_s^0 \rightarrow D_s^- \mu^+ X (D_s^- \rightarrow \phi\pi^-)$ yield.

The decay $B_s^0 \rightarrow D_s^- \mu^+ X (D_s^- \rightarrow K^{*0} K^-)$ has a branching ratio similar to $D_s^- \rightarrow \phi\pi^-$ but larger backgrounds. 4933 ± 376 such events have been reconstructed in $\sim$200 pb^{-1} of data (Fig. 2). Other decays including hadronic B_s^0 decays are being studied as well.

Other elements essential to a mixing analysis are given by the expression for the average statistical significance:

$$\mathrm{Significance}(\Delta \mathrm{m_s}, \sigma_\mathrm{t}) = \sqrt{\frac{\mathrm{S}\epsilon \mathrm{D}^2}{2}} \sqrt{\frac{\mathrm{S}}{\mathrm{S}+\mathrm{B}}} \mathrm{e}^{-(\Delta \mathrm{m_s} \sigma_\mathrm{t})^2/2} \tag{2}$$

where S is the number of signal events, B is the number of background events, σ_t is the proper time resolution and ϵ is the efficiency for applying the flavor tag with associated dilution, $\mathcal{D}$. Dilution is given by the following relation between the number of correctly and wrongly tagged events:

$$\mathcal{D} \equiv \frac{\mathcal{N}_{\mathrm{correct}} - \mathcal{N}_{\mathrm{wrong}}}{\mathcal{N}_{\mathrm{correct}} + \mathcal{N}_{\mathrm{wrong}}} \tag{3}$$

[a] Conjugate modes are implied throughout the paper

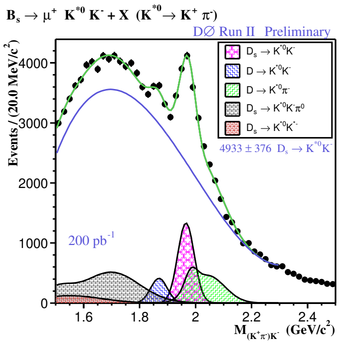

Fig. 2. $B_s^0 \to D_s^- \mu^+ X (D_s^- \to K^{*0} K^-)$ yield.

As indicated above, tagging the meson flavor (B_s^0 or $\bar{B}_s^0$) 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 Δm_d. Three tagging algorithms have been developed so far: opposite-side soft lepton (muon) tagging (SLT), same-side (soft-pion) tagging (SST), and opposite-side jet charge tagging (jetQ).

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_d^0 mixing studies - $B_d^0 \to D^{*-} \mu X$ where $D^{*-} \to \bar{D}^0 \pi^-$ and $\bar{D}^0 \to K^+ \pi^-$ - 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. 3 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 ± 0.2 % and $\mathcal{D} = 46.0 \pm 4.2$ % .

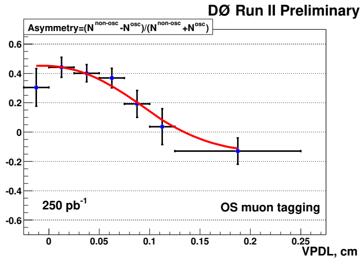

Fig. 3. The asymmetry between the non-oscillated and oscillated mesons as a function of the visible proper decay length (Soft Lepton Tagging).

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_d^0) 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. Fig. 4 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 $\Delta m_d = 0.488 \pm 0.066 \pm 0.044$ ps^{-1} which is consistent with the world average.

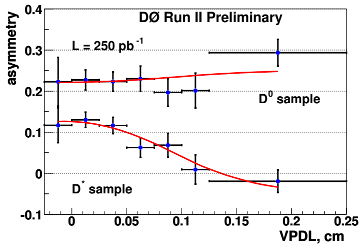

Fig. 4. The asymmetry between the non-oscillated and oscillated mesons as a function of the visible proper decay length (Same Side Tagging).

The opposite-side jet charge tagging algorithm calculates a p_T-weighted average charge of tracks: $jetQ \equiv \frac{\sum p_T{}^i q^i}{\sum p_T{}^i}$. A $|jetQ| < 0$ value corresponds to a b quark for the B meson on the opposite side, and vice-versa.

A simple combination of the above three tagging techniques was used to measure Δm_d using ~ 200 pb^{-1} of data. The dataset was split into two sub-samples with similar tagging power - one that was tagged by the soft muon (excellent dilution, low efficiency) and the other that was tagged by a combination of the same-side and jet-charge taggers (high efficiency, poor dilution). The combined same-side and jet-charge tagger produced a non-zero result for events that were not tagged by the SLT and for which at least one of SST or jetQ gave a non-zero answer. To further improve the dilution of the second subset, events for which jetQ and SST produced conflicting results on the initial state flavor were rejected. Fig. 5 shows the simultaneous fit to the SLT and SST+jetQ asymmetries which results in $\Delta m_d = 0.456 \pm 0.034 \pm 0.025$ ps^{-1}.

Lastly, since the significance scales as $e^{-(\Delta m_s \sigma_t)^2/2}$, for large values of Δm_s, a precise measurement of the proper decay time is crucial. Efforts are ongoing in this direction and we hope to combine all the above mentioned ingredients and arrive at a preliminary result for Δm_s soon.

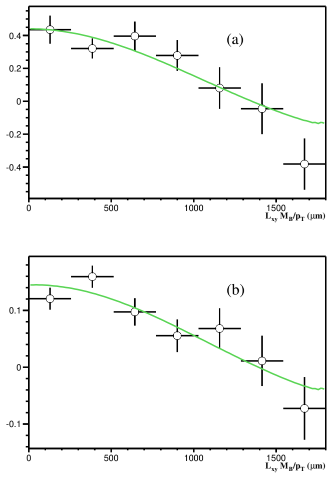

Fig. 5. The asymmetry between the non-oscillated and oscillated mesons as a function of the visible proper decay length: Soft Lepton Tagger (top), Same Side and Jet Charge combined tagger (bottom).

3. Conclusions

Preliminary measurements of Δm_d have 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}. The same side soft pion tagger yielded $\Delta m_d = 0.488 \pm 0.066 \pm 0.044$ ps^{-1}. The opposite side muon tagger, the same side soft pion tagger and the opposite side jet charge tagger were combined in a separate analysis to yield $\Delta m_d = 0.456 \pm 0.034 \pm 0.025$ ps^{-1}. These measurements, along with the development and optimization of other tagging algorithms, and the reconstruction of different B_s decay modes, are important steps towards a B_s mixing measurement.

References

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