PROCEEDINGS OF SCIENCE

Study of $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ and $B_s^0 \to \phi\phi$ Decays at CDF

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Under certain theoretical assumptions, the branching fraction of $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ is directly sensitive to the relative decay width difference $\Delta\Gamma_s^{CP}/\Gamma_s$ in the B_s^0 system, which is predicted to be sizable in the standard model. Using approximately 4 fb^{-1} of data collected by the CDF II detector at the Tevatron $p\bar{p}$ collider, the CDF collaboration is currently performing an exclusive selection of $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ signal candidates in several hadronic modes in order to provide a new branching fraction measurement. In contrast to former analyses, we start to have sensitivity in disentangling $D_s^{(*)+} D_s^{(*)-}$, enabling us to measure the branching fractions of $B_s^0 \to D_s^+ D_s^-$, $B_s^0 \to D_s^{*+} D_s^-$, and $B_s^0 \to D_s^{*+} D_s^{*-}$ separately. Yet another interesting mode is the decay of the B_s^0 into a ϕ pair. This is a vector-vector decay dominated by the $b \to s\bar{s}s$ penguin transition, which is a sensitive probe for possible new physics effects. Here we present a new measurement of the branching fraction based on a clean sample of about 300 $B_s^0 \to \phi\phi$ signal events in a dataset with an integrated luminosity of 2.9 fb^{-1}.

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1. Introduction

In the standard model (SM) of particle physics the rapidly oscillating $B_s^0 - \overline{B}_s^0$ system is characterised by a sizable decay width difference $\Delta\Gamma_s = \Gamma_s^L - \Gamma_s^H = 2\,|\Gamma_{12}|\cos\phi_s$ between the mass eigenstates B_s^L and B_s^H, and a vanishing CP violating phase $\phi_s = \arg(-M_{12}/\Gamma_{12})$. Here, M_{12} and Γ_{12} are the off-diagonal elements of the complex 2×2 mass matrix M and decay matrix Γ describing the time dependent B_s^0 mixing and decay problem. Since non-SM contributions could significantly increase ϕ_s [1], thus reducing $\Delta\Gamma_s$, there have been significant efforts in investigating possible new physics effects in the B_s^0 meson sector in recent years. A prominent example is $B_s^0 \to J/\psi\phi$: Based on an angular and time dependent analysis of a tagged $B_s^0 \to J/\psi\phi$ sample, both the CDF and DØ collaboration are intensely studying the CP violating phase $\beta_s^{J\psi\phi}$ and the decay width difference $\Delta\Gamma_s$. However, yet another type of $b \to c\bar{c}s$ decays, in particular $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$, can contribute in constraining the allowed parameter space, without adopting lifetime fits and sophisticated tagging techniques.

While the strongly CKM-favoured tree level $b \to c\bar{c}s$ decays are virtually insensitive to new physics, the situation is different for $b \to s\bar{s}s$ penguin transitions, where non-SM particles in the penguin loop could imply new CP-violating phases and affect the decay and mixing process. In this context, the decay $B_s^0 \to \phi\phi$ represents a sensitive probe for new physics effects. Testing the standard model expectation of the $B_s^0 \to \phi\phi$ branching fraction is a first preparative step towards additional interesting studies being on the agenda.

2. Future Prospects on the Study of $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ Decays at CDF

Assuming Γ_{12} to receive its dominant contribution by $b \to c\bar{c}s$ transitions into CP-specific final states, $2\,|\Gamma_{12}|$ equals $\Delta\Gamma_s^{CP} = \Gamma_s^{even} - \Gamma_s^{odd}$ [1]. Since $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ are favoured compared to $B_s^0 \to J/\psi\phi$ due to colour suppression, these decays give the largest contribution to the CP width difference in the B_s^0 system. Under certain theoretical assumptions [2], $D_s^{(*)+} D_s^{(*)-}$ is predominantly CP-even, and its branching fraction can directly be related to the relative CP width difference by $2\mathscr{B}[B_s \to D_s^{(*)+} D_s^{(*)-}] \cong \Delta\Gamma_s^{CP}/\Gamma_s$ [1]. However, the corrections associated with the limits introduced to neglect possible CP odd components can be sizable, as discussed in [1].

First evidence for these decays was reported by ALEPH [3]. Furthermore, DØ recently updated their semi-inclusive measurement of $\mathscr{B}[B_s \to D_s^{(*)+}(\phi\pi^+) D_s^{(*)-}(\phi\mu^-\bar{\nu}_\mu)]$ using data corresponding to 2.8 fb^{-1} [4], where no attempt was made to identify the photon or π^0 emanating from the $D_s^{*\pm}$ decay. Based on an exclusive reconstruction of the final states $D_s^+(\phi\pi) D_s^-(\phi\pi, K^{0*}K, 3\pi)$, the CDF collaboration reported first observation of $B_s \to D_s^+ D_s^-$. With about 24 signal events reconstructed in a data sample of 355 fb^{-1}, we extracted a branching fraction of $\mathscr{B}[B_s \to D_s^+ D_s^-] = [10.7^{+3.6}_{-3.3} \pm 1.0] \times 10^{-3}$ and obtained a lower bound on $\Delta\Gamma_s^{CP}/\Gamma_s$ [5].

With increased statistics now available, the CDF collaboration is currently updating this branching fraction measurement by reconstructing the same hadronic decay modes. For an advanced signal selection, we employ artificial neural networks. In addition to a common set of kinematic variables, we use particle identification (PID) variables being important for a good discrimination between kaons and pions. As an preliminary qualitative result, Figure 1 exemplarily shows the fitted invariant mass spectrum of $D_s^+(\phi\pi) D_s^-(\phi\pi)$ obtained by an unbinned maximum likelihood

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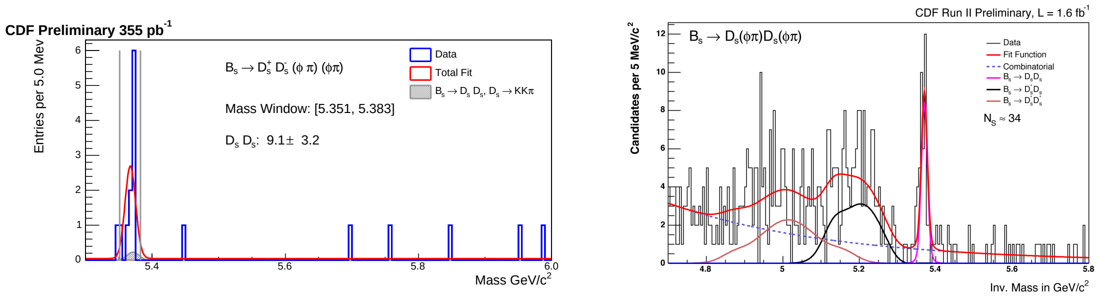

Figure 1: Invariant mass spectrum of the decay channel $B_s \to D_s^+(\phi\pi)D_s^-(\phi\pi)$ obtained from a 355 fb^{-1} data sample (left). Increased statistics now enable us to separate $D_s^+D_s^-$, $D_s^{*+}D_s^-$, and $D_s^{*+}D_s^{*-}$ (right).

fit. From this it appears that, in contrast to former measurements, we will be able to disentangle $D_s^{(*)+}D_s^{(*)-}$ and measure the branching fractions of $B_s^0 \to D_s^+D_s^-$, $B_s^0 \to D_s^{*+}D_s^-$, and $B_s^0 \to D_s^{*+}D_s^{*-}$ separately.

3. Measurement of the $B_s^0 \to \phi\phi$ Branching Fraction

The only existing sample of this mode has been reconstructed by the CDF experiment using 180 pb^{-1} of data [6]. Based on 8 signal events, $\mathscr{B}[B_s \to \phi\phi] = [1.4 \pm 0.6(stat) \pm 0.6(syst)] \cdot 10^{-5}$ was obtained, which is in reasonable agreement with the theoretical estimation $\mathscr{B}[B_s \to \phi\phi] = [2.18^{+0.11+3.04}_{-0.11-1.7}] \cdot 10^{-5}$ [7].

The CDF collaboration now presents an update of this measurement using displaced track trigger data corresponding to an integrated luminosity of 2.9 fb^{-1}. Due to similar decay topology and to suppress systematics, $\mathscr{B}[B_s \to \phi\phi]$ is measured relative to the branching fraction of the normalisation channel $B_s^0 \to J/\psi\phi$. ϕ meson candidates are formed from pairs of displaced oppositely charged kaon tracks. For $J/\psi \to \mu^+\mu^-$ positive identification of at least one muon candidate is required. In doing so, best compromise in respect of the signal-to-background ratio is achieved while the competing $J/\psi \to e^+e^-$ mode is being suppressed to a sufficient extent. Using five kinematic variables for each of the two decay modes, a cut based signal optimisation procedure is performed. For this we use simulated signal events N_S and background events N_B from the lower and upper sideband in data. The set of cuts maximising the figure of merit $S = N_S/\sqrt{N_S + N_B}$ is additionally validated using data only.

Using fixed shapes for the signal and physics background components obtained from simulation, binned maximum likelihood fits to the invariant mass distributions (see Figure 2) yield 295 ± 20 $\phi\phi$ and 1766 ± 48 $J/\psi\phi$ signal events. Using

$$\frac{\mathscr{B}[B_s \to \phi\phi]}{\mathscr{B}[B_s \to J/\psi\phi]} = \frac{N_{\phi\phi}}{N_{J/\psi\phi}} \cdot \frac{\varepsilon_{rec}^{J/\psi\phi}}{\varepsilon_{tot}^{\phi\phi}} \cdot \frac{\mathscr{B}[J/\psi \to \mu\mu]}{\mathscr{B}[\phi \to KK]} \cdot \varepsilon_{tot}^{\mu}, \tag{3.1}$$

where $\varepsilon_{rec}^{J/\psi\phi}/\varepsilon_{tot}^{\phi\phi}$ is the ratio of combined trigger and selection efficiencies determined from simulation and ε_{tot}^{μ} denotes the muon identification efficiency evaluated on $J/\psi \to \mu^+\mu^-$ displaced track trigger data, we obtain $\mathscr{B}[B_s \to \phi\phi] = [2.40 \pm 0.21(stat) \pm 0.27(syst) \pm 0.82(br)] \cdot 10^{-5}$, being in very good agreement with the theoretical prediction [7], which has very large hadronic

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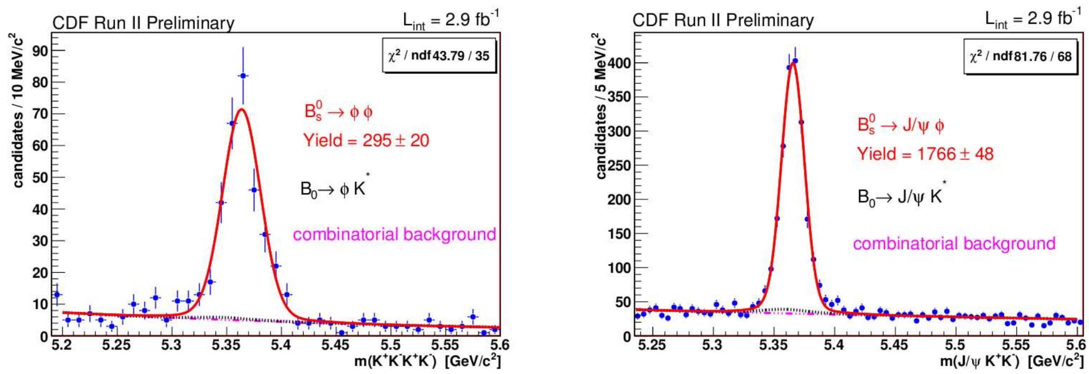

Figure 2: Final fits of the $B_s^0 \to \phi\phi$ (left) and $B_s^0 \to J/\psi\phi$ (right) invariant mass distributions. The black dotted lines show the small contributions of the $B^0 \to \phi K^*$ and $B^0 \to J/\psi K^*$ reflection, respectively, which appear if the final state pion of the decay $K^* \to K\pi$ happens to be misidentified as a kaon.

uncertainty, though. Due to the larger data sample available, a significant reduction by a factor of 5 in statistical uncertainty compared to the previous CDF measurement is achieved. However, the overall uncertainty is dominated by the large uncertainty stemming from the branching fraction of $B_s^0 \to J/\psi\phi$ [8]. The systematics considered include effects associated with the choice of fitting range, signal and physics background parameterisation, muon efficiency, and ratio of trigger and selection efficiencies due to effects not considered in simulation.

4. Conclusion and Outlook

With this new measurement, an important basis for future analyses is now established. With a large amount of additional CDF data to be expected in the near future, measurements of $\Delta\Gamma_s$ and $\beta_s^{\phi\phi}$ based on an angular and time dependant analysis, comparable to the $B_s^0 \to J/\psi\phi$ study, might come into reach. An amplitude analysis of $B_s^0 \to \phi\phi$, which allows testing of polarisation predictions and comparison to decays like $B^0 \to \phi K^*$, is already in preparation.

When it comes to $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$, provided sufficient statistics, lifetime measurements on these and additional double-charm data samples might help to experimentally control corrections associated with the theoretical assumptions [2], thus providing additional insights on $\Delta\Gamma_s$ [1].

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