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Partial Reconstruction of $B^0 \to D_s^{*+} D^{*-}$ Decays and Mesurement of the $D_s^+ \to \phi\pi^+$ Branching Fraction

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We present preliminary results on the branching fractions $\mathcal{B}(B^0 \to D_s^{*+} D^{*-})$ and $\mathcal{B}(D_s^+ \to \phi\pi^+)$, based on a data sample of approximately 124×10^6 $B\bar{B}$ events collected by the *BABAR* detector at the PEP-II e^+e^- B–factory. We reconstruct B^0 mesons using both a partial and a full reconstruction technique. We obtain the following preliminary results:

$$\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) = (1.85 \pm 0.09 \pm 0.16)\%$$
$$\mathcal{B}(D_s^+ \to \phi\pi^+) = (4.71 \pm 0.47 \pm 0.35)\%$$

where the first error in each measurement is statistical, the second systematic.

1. Introduction

A precise measurement of the branching fraction for the $D_s^+ \to \phi\pi^+$ mode is important because nearly all D_s branching fractions are determined by normalizing the measurements to $\mathcal{B}(D_s^+ \to \phi\pi^+)$ [1]. The present uncertainty of about 25% on $\mathcal{B}(D_s^+ \to \phi\pi^+)$ [2] thus affects many of the results regarding D_s mesons.

The data used in this analysis were collected with the *BABAR* detector [3] at the PEP-II storage ring and correspond to an integrated luminosity of $112.3 fb^{-1}$and to $(124 \pm 1) \times 10^6$ $B\bar{B}$ pairs.

2. Analysis method

In order to measure $\mathcal{B}(B^0 \to D_s^{*+} D^{*-})$ and $\mathcal{B}(D_s^+ \to \phi\pi^+)$ the $B^0 \to D_s^{*+} D^{*-} \to (D_s^+\gamma)(D^0\pi^-)$ decay is reconstructed using two different methods.

The first method uses a partial reconstruction technique, in which only the D^{*-} is fully reconstructed, and then combined with the soft photon from the $D_s^{*+} \to D_s^+\gamma$ decay, without requiring explicit D_s^+reconstruction. Denoting the measured event yield by N_{D_s}, we can express the $B^0 \to D_s^{*+} D^{*-}$branching fraction as:

$$\mathcal{B}_1 \equiv \mathcal{B}(B^0 \to D_s^{*+} D^{*-}) = \mathcal{K} \frac{N_{D_s}}{\sum_i (\epsilon_i \cdot \mathcal{B}_i^{D^0})}. \quad (1)$$

Here $\mathcal{K} \equiv [2N_{B^0\bar{B}^0}\mathcal{B}(D_s^* \to D_s^+\gamma)\mathcal{B}(D^{*-} \to D^0\pi^-)]^{-1}$, $N_{B^0\bar{B}^0}$is the number of neutral B meson pairs, $\mathcal{B}_i^{D^0}$ are the branching fractions for the D^0 decay modes and ϵ_i are the reconstruction and selection efficiencies for these modes.

$B^0 \to D_s^{*+} D^{*-}$decay can also be fully reconstructed. We focus on the $D_s^+ \to \phi\pi^+$mode, where the ϕ meson is reconstructed in the K^+K^- channel. From the measured yield $\mathcal{N}_{D_s\to\phi\pi}$we determine the product of branching fractions $\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) \cdot \mathcal{B}(D_s^+ \to \phi\pi^+)$ as:

$$\mathcal{B}_2 \equiv \mathcal{B}(B^0 \to D_s^{*+} D^{*-}) \cdot \mathcal{B}(D_s^+ \to \phi\pi^+) = \mathcal{K} \cdot \frac{\mathcal{N}_{D_s\to\phi\pi}}{\mathcal{B}(\phi \to K^+K^-) \sum_i (\epsilon'_i \cdot \mathcal{B}_i^{D^0})}, \quad (2)$$

where ϵ'_i is the efficiency for detecting the fully reconstructed B^0. The branching fraction $\mathcal{B}(D_s^+ \to \phi\pi^+)$ is measured from the ratio of the two yields:

$$\mathcal{B}(D_s^+ \to \phi\pi^+) = \frac{\mathcal{B}_2}{\mathcal{B}_1} = \frac{\mathcal{N}_{D_s\to\phi\pi} \sum_i (\epsilon_i \cdot \mathcal{B}_i^{D^0})}{N_{D_s} \mathcal{B}(\phi \to K^+K^-) \sum_i (\epsilon'_i \cdot \mathcal{B}_i^{D^0})}, \quad (3)$$

where the factor $\mathcal{K}$ exactly drops off, and although the efficiencies ϵ_i and ϵ'_i are in general different, many systematic uncertainties cancel out in the ratio.

3. Partial reconstruction

In order to extract the signal, we compute the missing mass $M_{\rm miss}$ recoiling against the $D^{*-} - \gamma$ system (all quantities defined in the center-of-mass (CM) frame):

$$M_{\rm miss} = \sqrt{(E_{\rm beam} - E_{D^*} - E_\gamma)^2 - (\mathbf{p}_B - \mathbf{p}_{D^*} - \mathbf{p}_\gamma)^2}. \quad (4)$$

To reject events from continuum, we require the ratio of the second to the zeroth Fox-Wolfram moment (R_2) [4] to be less than 0.3. Candidates $D^{*-}$are selected requiring 1.4 GeV/$c < p_{D^*}^{CMS} <$ 1.9 GeV/c, the D^0 reconstructed mass to be within 3 standard deviations $\sigma_{m_{D^0}}$ of the nominal value $m_{D^0}^{PDG1}$, and $Q_{D^*} \equiv m_{D^*} - m_{D^0} - m_{\pi^-}$ to satisfy $Q_{\rm lo} < Q_{D^*} < Q_{\rm hi}$, where the limits $Q_{\rm lo}$ = 4.10 to 5.20 MeV/c^2 and $Q_{\rm hi}$ = 6.80 to 7.90 MeV/c^2 are chosen around the nominal value $Q_{D^*}^{PDG} = 5.851$ MeV/c^2 depending on the D^0 decay mode. If more than one D^{*-}candidate is found, for each D^0 decay mode we choose the best one based on the minimum value of $\chi^2(m_{D^0}, m_{D^*})$, and if candidates from different D^0 decay modes are present, we select the one with the best expected purity. In order to select the photon we require E_γ^{CMS} >142 MeV, a minimum cluster lateral moment [5] of 0.016, and a minimum Zernike moment [6] of order $\{2,0\}$ of 0.82. If more than one photon is selected we choose the one that maximizes the value of a likelihood ratio based on the photon variables. The signal reconstruction efficiency is determined from a Monte Carlo sample of $B^0 \to D_s^{*+} D^{*-}$events. We extract the signal yield from the data sample by performing an unbinned maximum likelihood fit to the missing mass distribution. The signal peak is well described by a Gaussian probability density function (p.d.f.), while the background is parametrized with the function $B(M_{\rm miss}) = B_0(1 - e^{-(M_{\rm miss} - m_{\rm max})/b})(M_{\rm miss}/m_{\rm max})^c$, where $m_{\rm max}$ is the end point of the missing mass distribution. The result of the fit is shown in Fig.1. The signal yield is 7414 ± 345 events, corresponding to a branching fraction:

$$\mathcal{B}(B^0 \to D_s^{*+} D^{*-}) = (1.85 \pm 0.09_{stat} \pm 0.16_{syst})\%. \quad (5)$$

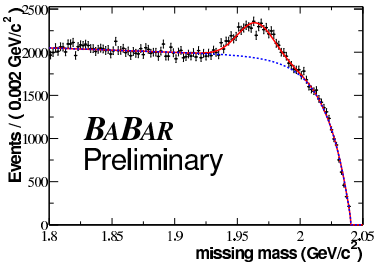

Fig. 1. Fir to $M_{\rm miss}$ final distribution.

that is compatible with, and improves on the precision of previously published experimental results [1,7], and may be compared with the most recent theoretical results based on the factorization assumption [8]: $\mathcal{B}(B^0 \to D_s^{*+}D^{*-})_{\rm theor} = (2.4 \pm 0.7)\%$.

4. Full reconstruction analysis

In order to extract the number of fully reconstructed B^0 we compute the energy-substituted mass $M_{\rm ES} = \sqrt{E^2_{\rm beam} - (\mathbf{p}_{D^*} + \mathbf{p}_{D_s^*})^2}$, where $\mathbf{p}_{D^*}$ and $\mathbf{p}_{D_s^*}$ are the $D^{*-}$and D_s^{*+}momenta in the CM frame.

For the candidates selection we require the reconstructed ϕ mass to be between 1.0077 and 1.0347 GeV/c^2, the $m_{D_s^*} - m_{D_s}$ mass difference to be between 0.125 and 0.160 GeV/c^2, $|\cos\vartheta_K| > 0.35$ [a], $E_\gamma^{\rm CMS} > 0.09$ GeV, and $|\Delta E| \equiv |(E_{D^*} + E_{D_s^*}) - E_{\rm beam}| < 0.05$ GeV.

We determine the selection efficiency fitting the $M_{\rm ES}$ distribution of the signal Monte Carlo sample with a Crystal Ball function [9]. Monte Carlo studies show the presence of a peaking contribution due to real $B^0 \to D_s^{*+}D^{*-} \to (D_s\gamma)(D^0\pi^-)$ events, where either the D^0 does not decay to the reconstructed modes, or the D_s does not decay to $\phi\pi^+$.

The total $M_{\rm ES}$ distribution is fitted with the sum of a Crystal Ball and an Argus function [10], accounting for the combinatorial background (Fig.2). The signal yield, after peaking subtraction, is $S_{\rm tot} = (212 \pm 19)$, corresponding to $\mathcal{B}_2 = \mathcal{B}(B^0 \to D_s^{*+}D^{*-}) \cdot \mathcal{B}(D_s^+ \to \phi\pi^+) = (8.71 \pm 0.78_{stat}) \times 10^{-4}$.

Finnaly we mesure the $\mathcal{B}(B^0 \to D_s^{*+}D^{*-})$ from Eq.3. In the ratio many systematic uncertainties cancel out. All other sources are listed in Table 1 and we obtain:

$$\mathcal{B}(D_s^+ \to \phi\pi^+) = (4.71 \pm 0.47_{stat} \pm 0.35_{syst})\%, \qquad (6)$$

This new determination improves on published results [2,11,12].

[a] the helicity angle ϑ_K is defined as the angle between the kaon direction in the ϕ rest frame and the ϕ meson direction in the D_s frame.

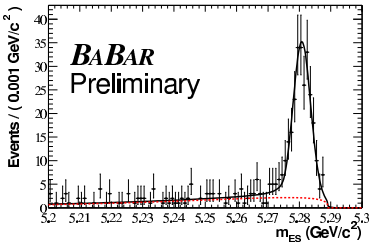

Fig. 2. Fit to $M_{\rm ES}$ final distribution.

Table 1. Sources of systematic error (%) for the determination of $\mathcal{B}(D_s \to \phi\pi^+)$

Source	Error (%)
Monte Carlo statistics	0.6
p.d.f. modelling	4.5
B counting	1.1
Tracking efficiency	2.4
Soft pion efficiency	1.6
Vertexing	2.0
Photon efficiency	4.6
Particle identification	0.9
Polarization uncertainty	0.8
D^0 branching fractions	3.2
$\mathcal{B}(D^{*-} \to D^0\pi^-)$	0.7
$\mathcal{B}(D_s^* \to D_s\gamma)$	2.7
Total systematic error	8.6

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