Fully Reconstructed B-Meson Decays
Using J/ψ and ψ (2S)

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Fully Reconstructed B-meson Decays Using $J/\psi$ and $\psi(2S)$

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In this paper we present CDF B-meson branching ratio results involving color-suppressed $B \to \psi K$ decays, where $\psi = J/\psi, \psi(2S)$ and $K = K, K^*$. Fully reconstructed decays of $B \to J/\psi K, B \to \psi(2S)K, B^+ \to J/\psi \pi^+ \pi^-$ and $B_s \to J/\psi \phi$ are used to extract branching ratios, vector-pseudoscalar ratios and polarization parameters.

1 Introduction

The decay of $B \to \psi K$ is expected to proceed primarily through the 'color-suppressed' $b \to c\bar{c}s$ diagram. The determination of its magnitude and decay mechanism provide insight into the hadronic $B$ decays. Under the factorization assumption, the branching ratios of $B \to \psi K$ decay modes depend only on $\alpha_2$, where $\alpha_2$ is the amplitude of internal $W$-decay in $B$ hadrons. Precise measurements of exclusive $B \to \psi K$ will be useful to determine $\alpha_2$ and ultimately test the factorization assumption.

The large $b$ production cross section at the Tevatron and the successful implementation of lepton triggers have enabled CDF to join this area of highly competitive $b$ physics. We report here new results from CDF on the branching ratio measurements of $B \to \psi K$ decays. The data were taken during the 1992-1995 runs with the CDF detector (RUN-I) and the integrated luminosity is 110 pb$^{-1}$.

2 $J/\psi$ and $\psi(2S)$ reconstruction

The data sample used for the inclusive $\psi$ reconstruction was selected by a three-level trigger system in which two opposite-charged muons with an invariant mass between 2.7 and 4.1 GeV/$c^2$ were required. A least-squares fit was performed on the two muon candidate tracks constraining the two tracks to originate from a common vertex. Muon candidates were required to possess $p_t > 2$ GeV/$c$ before any vertex constraints were imposed on the track parameters. In the case of $\psi(2S) \to J/\psi \pi^+ \pi^-$ reconstruction, all four legs were required to originate from a common vertex. The pre-constrained dipion invariant mass was required to lie in the range $0.31 < M_{\pi \pi} < 0.61$ GeV/$c$ to reduce combinatorial background.

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The excellent triggering, tracking and vertexing at CDF can be demonstrated by the inclusive $J/\psi \rightarrow \mu^+\mu^-$. $\psi(2S) \rightarrow \mu^+\mu^-$ and $\psi(2S) \rightarrow J/\psi \pi^+\pi^-$ mass distributions shown in Fig. 1 and Fig. 2.

![Figure 1: The $J/\psi$ dimuon invariant mass distribution after a vertex constraint.](image1)

![Figure 2: The $\psi(2S)$ dimuon (left) and $J/\psi\pi\pi$ (right) invariant mass distributions after a vertex constraint.](image2)

3 $B \rightarrow J/\psi K$

After mass constraining its mass to the world average value, the $J/\psi$ is combined with a $K$ to look for $B$-mesons where $K = K^+,K^0,K^*(892)^0, or K^*(892)^+$. We reconstruct $K^0$ through $K^0$. The $K^0$ selection requires two oppositely charged tracks with $p_t > 0.35\text{GeV}/c$ and the pairs are vertex constrained. The $K^*(892)^+$ is formed with a $K^0$ candidate plus a track, assumed to be a $\pi^-$; the $K^*(892)^0$ is formed from two charged tracks assumed to be a $K^+$ and $\pi^-$. The $K^*(892)^+ and K^*(892)^0$ candidates are required to have an invariant mass within 75 MeV/c² of the PDG value.
The invariant mass spectra of $B^+$ and $B^0$ using 19.6 pb$^{-1}$ data (RUN-1A) are shown in Fig 3 and Fig 4. The number of events from fitting and the relative reconstruction efficiency from Monte Carlo study are listed in Table 1.

Table 1. $B \rightarrow J/\psi K$ result

<table>
<thead>
<tr>
<th></th>
<th>$B^+ \rightarrow J/\psi K^+$</th>
<th>$B^0 \rightarrow J/\psi K^0$</th>
<th>$B^0 \rightarrow J/\psi K^*(892)^0$</th>
<th>$B^+ \rightarrow J/\psi K^*(892)^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_e$</td>
<td>$169 \pm 18$</td>
<td>$41.8 \pm 6.9$</td>
<td>$71 \pm 12$</td>
<td>$17.0 \pm 4.7$</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>1.0</td>
<td>1.57 $\pm$ 0.08</td>
<td>2.11 $\pm$ 0.18</td>
<td>2.53 $\pm$ 0.37</td>
</tr>
</tbody>
</table>

The ratios of branching ratios are: $\frac{B_r(B^0 \rightarrow J/\psi K^0)}{B_r(B^+ \rightarrow J/\psi K^+)} = 1.13 \pm 0.22 \pm 0.06$, $\frac{B_r(B^0 \rightarrow J/\psi K^*)}{B_r(B^+ \rightarrow J/\psi K^+)} = 1.33 \pm 0.27 \pm 0.11$ and $\frac{B_r(B^+ \rightarrow J/\psi K^+)}{B_r(B^+ \rightarrow J/\psi K^+)} = 1.55 \pm 0.46 \pm 0.16$.

Using the world average $B_r(B^+ \rightarrow J/\psi K^+) = (0.102 \pm 0.014)\%$\textsuperscript{2}, we find

$B_r(B^0 \rightarrow J/\psi K^0) = (0.115 \pm 0.023 \pm 0.017)\%$

$B_r(B^0 \rightarrow J/\psi K^0) = (0.136 \pm 0.027 \pm 0.022)\%$

$B_r(B^+ \rightarrow J/\psi K^+) = (0.158 \pm 0.047 \pm 0.027)\%$

Assuming isospin symmetry, we combine the above results to extract the vector-pseudoscalar ratio

$R = \frac{B_r(B \rightarrow J/\psi K^*)}{B_r(B \rightarrow J/\psi K)} = 1.32 \pm 0.23 \pm 0.16$.

CDF has published a measurement of $J/\psi$ polarization\textsuperscript{4} in $B^0 \rightarrow J/\psi K^*(892)^0$, $\Gamma_L/\Gamma = 0.65 \pm 0.10 \pm 0.04$.

It will be interesting to see whether theory models based on the factorization hypothesis and the $B \rightarrow K(K^*)$ form factors can reproduce the above results.
4 $B^+ \to J/\psi \pi^+$

The difficult task here is to distinguish the small $B^+ \to J/\psi \pi^+$ signal from large backgrounds. We estimate the signal mass spectrum and background spectra from $B^+ \to J/\psi K^+$, misidentifying the $K^+$ as a $\pi^+$, and combinatorial background using Monte Carlo. From a fit to the $J/\psi \pi^+$ mass spectra, shown in Fig. 5, we find $28_{-9}^{+19}$ events with a 3.0$\sigma$ significance. The branching ratio relative to $B^+ \to J/\psi K^+$ is extracted to be

$$
\frac{Br(B^+ \to J/\psi \pi^+)}{Br(B^+ \to J/\psi K^+)} = (6.0^{+2.2}_{-2.0} \pm 0.1)\% 
$$

![CDF Preliminary](image_url)

Figure 5: The $M_{J/\psi \pi^+}$ mass distribution. The superimposed curves show the $M_{J/\psi \pi^+}$ distribution for Monte Carlo $B^+ \to J/\psi K^+$ and combinatorial events. There is clearly an excess around the $B$ mass region which is due to the contribution of $B^+ \to J/\psi \pi^+$ decay.

5 $B \to \psi(2S)K$

Using the full available dataset and similar techniques for $B \to J/\psi K$ decay, we reconstructed decays of $B^+ \to \psi(2S)K^+$ and $B^0 \to \psi(2S)K^*(892)^0$ as shown in Fig. 6 and Fig. 7. We use the $B^+ \to J/\psi K^+$ and $B^0 \to J/\psi K^*(892)^0$ as normalization modes. We find:

$$
\frac{Br(B^+ \to \psi(2S)K^+)}{Br(B^+ \to J/\psi K^+)} = 0.666 \pm 0.093 \pm 0.101
$$

$$
\frac{Br(B^0 \to \psi(2S)K^*)}{Br(B^0 \to J/\psi K^*)} = 0.569 \pm 0.131 \pm 0.074
$$
Figure 6: The $\psi(2S)K^+$ invariant mass distribution with $\psi(2S) \rightarrow \mu^+\mu^-$ (left) and $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$ (right). The numbers of events are 83 ± 14 and 35 ± 7 respectively for the two decay channels.

Figure 7: The $\psi(2S)K^+(892)^0$ invariant mass distribution with $\psi(2S) \rightarrow \mu^+\mu^-$ (left) and $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$ (right). The numbers of events are 23 ± 8 and 25 ± 7 respectively for the two decay channels.

Using $Br(B^+ \rightarrow J/\psi K^+)$ = (0.102 ± 0.014)% and $Br(B^+ \rightarrow J/\psi K^{*0})$ = (0.158 ± 0.28)%², we find $Br(B^+ \rightarrow \psi(2S)K^+)$ = (6.8 ± 1.0 ± 1.4) × 10⁻⁴ and $Br(B^0 \rightarrow \psi(2S)K^{*0})$ = (9.0 ± 2.1 ± 2.0) × 10⁻⁴. From isospin symmetry and $r^+/r^0 = 1.02 ± 0.05$², we calculate the vector-pseudoscalar ratio

$$R = \frac{Br(B \rightarrow \psi(2S)K^*)}{Br(B \rightarrow \psi(2S)K)} = 1.35 ± 0.55$$

which is consistent with $R$ calculated with $B \rightarrow J/\psi$ decays.

6 $B_s \rightarrow J/\psi\phi$

The decay of $B_s \rightarrow J/\psi\phi$ is expected to be dominated by CP-even state and the decay is of special interest to extract CP violation in the $B_s$ system. From a data sample of 19.6 $pb^{-1}$, we find 29.4 ± 6.2 events of $B_s \rightarrow J/\psi\phi$ with $\phi \rightarrow K^+K^-$, as show in Fig. 8. Using the well measured $B \rightarrow J/\psi K$ as the normalization mode and their world averaged branching ratio, we find

$$Br(B_s \rightarrow J/\psi\phi) = \frac{f_s}{f_u + f_d} (0.037 ± 0.011 ± 0.004)\%$$
where $f_u, f_d$ and $f_s$ are fragmentation fraction of $b$ quarks to $B_u, B_d$ and $B_s$ mesons. Using $f_s/(f_u + f_d) = (0.20 \pm 0.03)^5$, we have

$$ Br(B_s \to J/\psi \phi) = (0.093 \pm 0.028 \pm 0.017)\%.$$ 

Figure 8: The $J/\psi \phi$ invariant mass distribution.

7 Summary

Using CDF dimuon sample, we measured B-meson branching ratios involving color-suppressed $B \to \psi K$ decays, $B \to J/\psi \pi$ and $B_s \to J/\psi \phi$. The vector-pseudoscalar ratios for $B \to J/\psi$ and $B \to \psi(2S)$ are extracted to be $1.32 \pm 0.23 \pm 0.16$ and $1.35 \pm 0.55$ respectively. Much effort is still being put into updating the above results using the full RUN-I data sample. We can expect excellent new results in the near future.

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