Branching Ratios from $B_s$ and $\Lambda_b^0$

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CDF Run II relative branching ratio measurements for $65 \text{ pb}^{-1}$ of data in the channels $B_s \rightarrow D_s^\mp \pi^\pm$, $\Lambda_b^0 \rightarrow \Lambda_c^\pm \pi^\mp$ and $B \rightarrow h^+ h^-$ are presented. Further, an observation of $B_s \rightarrow K^\pm K^\mp$ and a measurement of $A_{CP}$ are presented.

1 Introduction

CDF Run II, and D0 are a unique opportunity to pursue a rich program of B-Physics. Until LHCb or BTEV become operational, CDF and D0 are the only experiments currently taking data that can access the B-baryons and the heavier (than $B_d$) B-mesons. A precision study of the $B_s$ is currently underway. Branching ratios, mass and lifetime are all being measured. A measurement that would either observe or rule out SM $B_s$ mixing is planned. Measurements of $\Delta \Gamma_{B_s}$ and $\gamma$ are also envisaged. CDF also has the world’s largest $\Lambda_b^0$ sample. Branching ratio, mass and lifetime measurements are already underway, or planned in the near future. In the present paper, relative branching ratio results for $65 \text{ pb}^{-1}$ of data are presented for the channels $B_s \rightarrow D_s^\mp \pi^\pm$, $\Lambda_b^0 \rightarrow \Lambda_c^\pm \pi^\mp$ and $B \rightarrow h^+ h^-$. 

2 Hadronic Level 2 Trigger

The hardware that enables CDF to observe the fully hadronic B signals presented here is the SVT\cite{1} (Second level Vertex Trigger).\footnote{The CDF detector is described elsewhere\cite{2}} The interaction rate at CDF is approximately $2.5 \text{ MHz}$. This has to be reduced to a rate of the order $300 \text{ Hz}$ to be written to tape. The critical component of the hadronic trigger path are the impact parameter cuts made by the SVT at level 2. The SVT uses the Silicon detector data with the level-1 tracking information from the central tracking chamber. The heart of the algorithm is a parallel look-up operation of previously computed acceptable hit patterns. The legitimate hit patterns are then fed into a Track Fitter stage which gives track parameters curvature, $\phi_0$ and most importantly impact-parameter. The two hadronic trigger streams which are implemented at CDF are $B \rightarrow h^+ h^-$ and B-multibody respectively\cite{3}. The impact parameter requirement for the $B \rightarrow h^+ h^-$ stream is two tracks with $d_0 > 100 \mu m$, while the B-multibody stream requires two tracks with $d_0 > 120 \mu m$. A plot of the SVT impact-parameter distribution is given in figure 1.
Figure 1: Level 2 SVT impact parameter distribution (µm)

3 Branching Ratios at CDF

At CDF, a branching ratio measurement is quoted as a ratio of branching ratios. For example, in the case of $B_s \rightarrow D_s^{+\pi^\pm}$, the quantity quoted is:

$$\frac{\sigma_b \times f_s \times BR (B_s \rightarrow D_s^{+\pi^\pm})}{\sigma_b \times f_d \times BR (B_d \rightarrow D^{\mp\pi^\pm})} = \frac{\epsilon_{B_s} \times N_{B_s} \times BR (D^- \rightarrow K^-\pi^+\pi^-)}{\epsilon_{B_d} \times N_{B_d} \times BR (D^+_s \rightarrow \phi\pi^-)}$$

(1)

where $f_s$, $f_d$ are B-meson production fractions, and $\epsilon_{B_s}$, $\epsilon_{B_d}$ are total observation efficiencies (trigger and reconstruction). The primary advantage of this is that the systematic uncertainties due to the trigger and reconstruction efficiencies cancel. Furthermore, the b production cross-section cancels. At present, the B-meson production fractions used are the LEP/CDF combined results[4]. However, it is intended that these be measured at CDF Run II. Currently existing measurements are used for the daughter branching ratios. However, it is planned to normalise to the same channel semileptonic modes so that the daughter branching ratios would then cancel.

4 $B_d \rightarrow D^{\mp\pi^\pm}$

The channel $B_d \rightarrow D^{\mp\pi^\pm}$ is the normalisation mode for both $B_s \rightarrow D_s^{+\pi^\pm}$ and $A^0_b \rightarrow A^{\pm\pi^\pm}_{c}$. The reconstruction cuts for the normalisation mode are chosen to be as similar as possible to the signal mode cuts (to ensure the best cancellation of systematic errors). For the $B_s \rightarrow D_s^{+\pi^\pm}$ analysis, the selection requirements for the normalisation mode are as follows. First the trigger is confirmed by requiring that 2 of the 4 offline tracks be associated to SVT trigger tracks. Further the $p_t$, charge, transverse angle, and impact parameter of these offline tracks are required to pass the trigger cuts. The reconstruction cuts are then: [The $D^\pm$ and $B_d$ are reconstructed
using a kinematic fitter; [The \( D^\pm \) mass is constrained to the PDG value]; \( \Delta R (D^\pm \pi_B) < 1.5 \) (where \( \pi_B \) is the pion from the B)]; \( |\chi_{xy}^{B_d} < 15, \chi_{xy}^{D^\pm} < 10| \); \( p_t^{D^\pm} > 4 GeV, \) and \( p_t^{B_d} > 6 GeV \); \( L_{xy}^{D^\pm} > 600 \) \( \mu m \), \( L_{xy}^{B_d} > 100 \mu m \) \(^2\); [The impact parameter for the fully reconstructed \( B_d \) meson is required to satisfy \( |b_{B_d}| < 100 \mu m \) The invariant mass distribution obtained can be seen in figure 2. The smaller structure on the left is due to the mode \( B_d \rightarrow D^{*^-} \pi^+ \).

Figure 2: Invariant mass distribution of \( B_d \rightarrow D^{\mp} \pi^\pm \), with the \( D^{*^-} \) visible on the left.

5 \( B_s \rightarrow D_s^{\mp} \pi^\pm \)

The selection requirements for the \( B_s \rightarrow D_s^{\mp} \pi^\pm \) signal are identical to the \( B_d \rightarrow D^{\mp} \pi^\pm \) normalisation mode, except for the \( L_{xy} \) cuts\(^3\) on the \( B_s \) and \( D_s \), and an invariant mass cut on the \( \phi \) from the \( D_s \) \( (D_s \rightarrow \phi \pi)^4 \). The invariant mass distribution obtained can be seen in figure 3. As with the \( B_d \rightarrow D^{\mp} \pi^\pm \) mass plot, the excited charm-meson state can be seen on the left hand side of the plot. The systematic uncertainties of the analysis are summarized in table 1. The branching ratio result is then:

\[
\frac{f_s \times BR (B_s \rightarrow D_s^{\mp} \pi^\pm)}{f_d \times BR (B_d \rightarrow D^{\mp} \pi^\pm)} = 0.42 \pm 0.11 (stat) \pm 0.11 (BR) \pm 0.07 (syst) \tag{2}
\]

where the systematic uncertainty from the external \( B_d \rightarrow D^{\mp} \pi^\pm \) daughter branching ratio and the analysis are quoted separately. Using the PDG\(^4\) measurement:

\[
\frac{f_s}{f_d} = 0.273 \pm 0.034 \tag{3}
\]

\(^2\)where each \( L_{xy}^X = \frac{p_{xy}^2}{2} \cdot \frac{\vec{X}_{PV} \cdot \vec{X}_{PV}}{\vec{X}_{PV} \cdot \vec{X}_{PV}} \) is calculated with respect to the primary vertex \( \vec{X}_{PV} \).

\(^3\)\( L_{xy}^{D^\pm} > 400 \mu m, \ L_{xy}^{B_d} > 100 \mu m \)

\(^4\)\( m (K^+ K^-) \in [1.013, 1.028] \) GeV
the result becomes:

$$\frac{BR(B_s \to D_s^{\mp} \pi^\pm)}{BR(B_d \to D^{\mp} \pi^\pm)} = 1.61 \pm 0.40(\text{stat}) \pm 0.40(\text{BR}) \pm 0.26(\text{syst}) \pm 0.20 \left(\frac{PDG f_s}{f_d}\right)$$ (4)

![Invariant mass distribution of $B_s \to D_s^{\mp} \pi^\pm$, with the $D_s^{*-}$ visible on the left.](image)

Figure 3: Invariant mass distribution of $B_s \to D_s^{\mp} \pi^\pm$, with the $D_s^{*-}$ visible on the left.

<table>
<thead>
<tr>
<th>Particle</th>
<th>$\sigma\left(\frac{N_{B_s}}{N_{B_d}}\right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s$</td>
<td>$\pm 0.008$</td>
</tr>
<tr>
<td>$B_d$</td>
<td>$\pm 0.008$</td>
</tr>
</tbody>
</table>

Fit systematics

<table>
<thead>
<tr>
<th>Source</th>
<th>$\sigma\left(\frac{\epsilon_{B_s}}{\epsilon_{B_d}}\right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>XFT 1-2-3 [3]</td>
<td>$-0.00 + 0.001$</td>
</tr>
<tr>
<td>Min b quark $p_t$</td>
<td>$-0.08 + 0.00$</td>
</tr>
<tr>
<td>B lifetimes</td>
<td>$-0.02 + 0.04$</td>
</tr>
<tr>
<td>D lifetimes</td>
<td>$-0.00 + 0.04$</td>
</tr>
<tr>
<td>Total</td>
<td>$-0.08 + 0.06$</td>
</tr>
</tbody>
</table>

Monte Carlo Systematics

Table 1: $B_s \to D_s^{\mp} \pi^\pm$ systematic uncertainties. The left table gives the contributions due to the fit for the number of events. The right table gives the contributions due to the Monte-Carlo calculation of the reconstruction efficiencies.

6 $\Lambda_b^0 \to \Lambda_c^{\pm} \pi^{\mp}$

As with the $B_s \to D_s^{\mp} \pi^\pm$ analysis, there is a trigger confirmation required on the offline tracks. The analysis cuts are then: $[p_t(P) > 2$ GeV$]$; $[p_t(\pi \text{ from } \Lambda_c^0) > 2$ GeV$]$; $[p_t(\Lambda_c^0) > 7.5$ GeV$]$; $[p_t(\Lambda_c^{\pm}) > 4.5$ GeV$]$; $[ct(\Lambda_c^0) > 225$ $\mu$m$]$; $[ct(\Lambda_c^{\pm} \text{ from } \Lambda_c^0) > -65$ $\mu$m$]$; [Impact-Par $(\Lambda_c^0) < \ldots$]
The signal region is calculated from pseudorapidity and the size of the contribution in the area with the amount

\[ [\Delta \eta, \Delta \phi] \]

The results are then \( \eta + \eta \rightarrow B \)

\( \pm \sqrt{2} V \rightarrow \eta V \)

\( \eta + \eta \rightarrow B \)

\( \pm \sqrt{2} V \rightarrow \eta V \)

\( \eta + \eta \rightarrow B \)

The result becomes

\( 0.03 \pm 0.05 \)

The signal region is calculated from pseudorapidity and the size of the contribution in the area with the amount

\( \eta + \eta \rightarrow B \)

\( \pm \sqrt{2} V \rightarrow \eta V \)

The result is then

\( 0.03 \pm 0.05 \)
<table>
<thead>
<tr>
<th>Variable</th>
<th>Central Value</th>
<th>Variation Range</th>
<th>(% Change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0$ lifetime ($\mu$m)</td>
<td>462</td>
<td>457 − 467</td>
<td>±0</td>
</tr>
<tr>
<td>$A^0_b$ lifetime ($\mu$m)</td>
<td>369</td>
<td>345 − 393</td>
<td>+4 − 5</td>
</tr>
<tr>
<td>$A^+_c$ Dalitz structure</td>
<td>nonresonant</td>
<td></td>
<td>+1</td>
</tr>
<tr>
<td>$p_t$ spectrum</td>
<td>0</td>
<td>±1</td>
<td>+1</td>
</tr>
<tr>
<td>$A^0_b$ polarization</td>
<td>2 miss</td>
<td>1 miss</td>
<td>+3</td>
</tr>
<tr>
<td>XFT[3]</td>
<td></td>
<td></td>
<td>±3</td>
</tr>
<tr>
<td>$\phi$ efficiency</td>
<td></td>
<td></td>
<td>±7</td>
</tr>
<tr>
<td>subtotal</td>
<td></td>
<td></td>
<td>±9</td>
</tr>
</tbody>
</table>

Table 2: Systematic uncertainties for the $A^0_b \rightarrow A^+_c\pi^-$ BR measurement.

The invariant mass distribution obtained can be seen in figure 5, and a monte-carlo distribution of the various signal components is shown in figure 6. This plot underlines how essential particle-ID is to the analysis since the different signal contributions lie almost on top of each other. The two forms of particle-ID employed are $dE/dx$ and kinematic separation. While kinematic separation is less effective than $dE/dx$, it is still useful. The two event variables used are the invariant mass with the pion hypothesis, and the variable $\alpha = \left(1 - \frac{p_{l}}{p_{2}}\right) q_{l}$, where $p_{1,2}$ are the particle momenta, $p_{1} < p_{2}$, and $q_{l}$ is the charge of the lower momentum particle. The more powerful $dE/dx$ information is calibrated on a $D^*$ sample where the bachelor $\pi$ charge identifies which of the $D^0$ daughters is the K, and which is the $\pi$. A separation plot can be seen in figure 7. The systematic uncertainties of the $B \rightarrow h^+ h^-$ analysis are summarised in table 3.

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Figure 6: $B \rightarrow h^+ h^-$ MC distribution showing different signal components

Figure 7: $dE/dx$ separation for the $D^*$ calibration sample.

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The $B \rightarrow \pi\pi$ and $B_s \rightarrow KK$ do in fact lie completely on top of each other.
The results are then:

\[
\frac{BR(B_d \to \pi^\pm \pi^\mp)}{BR(B_d \to K^\pm \pi^\mp)} = 0.26 \pm 0.11(\text{stat}) \pm 0.055(\text{syst}) \quad (8)
\]

\[
A_{CP} = \frac{(B_d^0 \to K^- \pi^+)}{(B_d^0 \to K^- \pi^+)} = 0.02 \pm 0.15(\text{stat}) \pm 0.017(\text{syst}) \quad (9)
\]

and a yield: \( B_s \to K^\pm K^\mp \) = 90 \pm 17(\text{stat}) \pm 17(\text{syst}) events, showing an observation in this channel.

<table>
<thead>
<tr>
<th>Effect</th>
<th>( \frac{BR(B_d \to \pi^\pm \pi^\mp)}{BR(B_d \to K^\pm \pi^\mp)} )</th>
<th>( A_{CP} (B_d \to K\pi) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bck. shape</td>
<td>+0.019 (-0.015)</td>
<td>+0.002 (-0.009)</td>
</tr>
<tr>
<td>( M(B_d) )</td>
<td>+0.004 (-0.004)</td>
<td>+0.0003 (-0.0003)</td>
</tr>
<tr>
<td>( M(B_s) )</td>
<td>+0.006 (-0.005)</td>
<td>+0.002 (-0.003)</td>
</tr>
<tr>
<td>Mass width</td>
<td>+0.004 (-0.009)</td>
<td>+0.006 (-0.005)</td>
</tr>
<tr>
<td>MC stat.</td>
<td>+0.002 (-0.002)</td>
<td>+0.007 (-0.007)</td>
</tr>
<tr>
<td>( dE/dx ) cal.</td>
<td>+0.05 (-0.05)</td>
<td>+0.01 (-0.01)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0.055</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Table 3: Systematic uncertainties for the \( B \to h^+\pi^- \) BR, and \( A_{CP} \) measurements. The \( dE/dx \) calibration dominates.

8 Conclusion

In conclusion, CDF has robust signals in the three channels: \( A_b^0 \to A_c^\pm \pi^\mp \), \( B_s \to D_\pi^\pm \pi^\mp \), and \( B_s \to K^\pm K^\mp \). The first measurements of the \( B_s \to D_\pi^\pm \pi^\mp \), and \( A_b^0 \to A_c^\pm \pi^\mp \) relative branching ratios have been made, and the the \( B_t \to K^\pm K^\mp \) signal is a first observation\(^8\). These constitute exciting first steps in the CDF programme for \( B_s^0 \) and \( A_b^0 \) physics.

References


\(^8\)The measurement of \( \frac{BR(B_s \to \pi^\pm \pi^\mp)}{BR(B_s \to K^\pm \pi^\mp)} \) validates the extraction procedure.