Branching Ratios from $B_s$ and $\Lambda_0^b$

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CDF Run II relative branching ratio measurements for 65 pb$^{-1}$ of data in the channels $B_s \to D_s^{\pm}\pi^\pm$, $\Lambda_0^b \to A_s^{\pm}\pi^\mp$ and $B \to h^+h^-$ are presented. Further, an observation of $B_s \to K^\pm K^\mp$ and a measurement of $A_{CP}$ are presented.

1 Introduction

CDF Run II is a unique opportunity to pursue a rich program of B-Physics. Until LHCb or BTEV become operational, CDF is the only experiment 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 $\Lambda_0^b$ 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 pb$^{-1}$ of data are presented for the channels $B_s \to D_s^{\pm}\pi^\pm$, $\Lambda_0^b \to A_s^{\pm}\pi^\mp$ and $B \to h^+h^-$.  

2 Hadronic Level 2 Trigger

The hardware that enables CDF to observe the fully hadronic B signals presented here is the SVT\[1\] (Second level Vertex Trigger).\footnote{The CDF detector is described elsewhere\[2\]} The interaction rate at CDF is approximately 2.5 MHz. This has to be reduced to a rate of the order 300 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 $B \to h^+h^-$ and B-multibody respectively\[3\]. The impact parameter requirement for the $B \to h^+h^-$ 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.
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 $B_s \rightarrow D_s^\mp \pi^\pm$, the quantity quoted is:

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

(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 $B_d \rightarrow D_s^\mp \pi^\pm$

The channel $B_d \rightarrow D_s^\mp \pi^\pm$ is the normalisation mode for both $B_s \rightarrow D_s^\mp \pi^\pm$ and $A_b^0 \rightarrow A_c^\mp \pi^\pm$. 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 $B_s \rightarrow D_s^\mp \pi^\pm$ 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]; [ΔR($D^\pm\pi_B$) < 1.5 (where $\pi_B$ is the pion from the B)]; [$\chi_B^{B_d} < 15$, $\chi_D^{D_s} < 10$]; [$p_T^{D^\pm} > 4$GeV, and $p_T^{B_d} > 6$GeV]; [$L_{xy}^{D_s} > 600$ $\mu$m, $L_{xy}^{B_s} > 100$ $\mu$m $2$]; [The impact parameter for the fully reconstructed $B_d$ meson is required to satisfy $|d_B| < 100$ $\mu$m$^3$]. The invariant mass distribution obtained can be seen in figure 2. The smaller structure on the left is due to the mode $B_d \rightarrow D^\pm \pi^\pm$.

![Invariant mass distribution](image)

Figure 2: Invariant mass distribution of $B_d \rightarrow D^\pm \pi^\pm$, 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:

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

(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:

$$\frac{f_s}{f_d} = 0.273 \pm 0.034$$

(3)

$^2$where each $L_{xy}^X = P_{xy}^z \cdot (X_{xy} - X_{PV})$ is calculated with respect to the primary vertex $(X_{PV})$.

$^3$L_{xy}^{D_s} > 400$ $\mu$m, $L_{xy}^{B_s} > 100$ $\mu$m

$^4$m($K^+K^\mp$) ∈ [1.013, 1.028] GeV
the result becomes:

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

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>
<th>Source</th>
<th>(\sigma \left( \frac{\epsilon_{B_s}}{\epsilon_{B_d}} \right) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B_s)</td>
<td>(\pm 0.008)</td>
<td>XFT 1-miss[3]</td>
<td>(-0.00 \pm 0.001)</td>
</tr>
<tr>
<td>(B_d)</td>
<td>(\pm 0.008)</td>
<td>Min b quark (p_t)</td>
<td>(-0.08 \pm 0.00)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B lifetimes</td>
<td>(-0.02 \pm 0.04)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D lifetimes</td>
<td>(-0.00 \pm 0.04)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>(-0.08 \pm 0.06)</td>
</tr>
</tbody>
</table>

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: \([p_t(P) > 2 \text{ GeV}]\); \([p_t(\pi \text{ from } \Lambda_c^0) > 2 \text{ GeV}]\); \([p_t(\Lambda_c^0) > 7.5 \text{ GeV}]\); \([p_t(\Lambda_c^0) > 4.5 \text{ GeV}]\); \([ct(\Lambda_c^0) > 225 \text{ \mu m}]\); \([ct(\Lambda_c^\pm \text{ from } \Lambda_b^0) > -65 \text{ \mu m}]\); [Impact-Par (\(\Lambda_b^0\) <
100 \, \mu m]; \, [2.265 < m(\Lambda^\pm_L) < 2.303)]. The signal invariant mass distribution obtained can be seen in figure 4. There are several different components to the unbinned likelihood fit shown. The red curve is the contribution from fully reconstructed B-decays with 4 daughters (like the signal).\(^5\) The sources of systematic error are given in table 2. The result is then:

\[
\frac{f_{\Lambda^0_b} \times BR(\Lambda^0_b \to \Lambda^\pm_L \pi^\mp)}{f_d \times BR(B_d \to D^\mp \pi^\pm)} = 0.66 \pm 0.11(stat) \pm 0.09(syst) \pm 0.18(BR) \tag{5}
\]

where the systematic uncertainty due to the external \(\Lambda^\pm_L\) branching ratio measurement and the analysis systematics are quoted separately. Using the PDG\[^4]\ measurement:

\[
\frac{f_{\text{baryon}}}{f_d} = 0.304 \pm 0.053 \tag{6}
\]

the result becomes:

\[
\frac{BR(\Lambda^0_b \to \Lambda^\pm_L \pi^\mp)}{BR(B_d \to D^\mp \pi^\pm)} = 2.2 \pm 0.4(stat) \pm 0.3(syst) \pm 0.7(BR + FR) \tag{7}
\]

where the last source of uncertainty is the combined effect of the external measurements of the \(\Lambda^\pm_L\) branching ratio and the production fraction ratio.

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\(^5\)This shape is calculated from monte-carlo, and the size of the contribution in the fit agrees with the amount of \(B_d \to D^\mp \pi^\pm\) observed in the \(\Lambda^0_b\) signal region.

\(^6\)Defined in a cone about the B axis : \(I = \frac{\sum_{B-\text{daughters}}(p_t)}{\sum_{All-\text{tracks}}(p_t)}\) (calibrated on data).

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**Figure 4:** \(\Lambda^0_b \to \Lambda^\pm_L \pi^\mp\) invariant mass distribution

**Figure 5:** \(B \to h^+h^-\) invariant mass distribution

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7 \hspace{1cm} B \to h^+h^-

The \(h^+h^-\) are required to be the trigger tracks. The analysis cuts are then: \([p_{t1} + p_{t2} > 5.5 GeV]; \, \left[\mid I P_1 \mid, \mid I P_2 \mid > 150 \, \mu m\right]; \, \left[2D-\text{Flight-Dist}(B) > 300 \mu m\right]; \, \left[\mid I P_B \mid < 80 \mu m\right]; \, \left[I \text{Isol}_B > 0.5\right].\)
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 \( \alpha = (1 - \frac{p_1^2}{p_2^2}) q_1 \), where \( p_1, p_2 \) are the particle momenta, \( p_1 < p_2 \), and \( q_1 \) 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 \( B \to h^+h^- \) analysis are summarised in table 3.

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<table>
<thead>
<tr>
<th>Event</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_0^0 ) lifetime (( \mu m ))</td>
<td>369</td>
<td>345 - 393</td>
<td>+4 - 5</td>
</tr>
<tr>
<td>( A_c^\pm ) Dalitz structure</td>
<td>nonresonant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( p_t ) spectrum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( A_0^0 ) polarization</td>
<td>0</td>
<td>±1</td>
<td>±7</td>
</tr>
<tr>
<td>XFT[3]</td>
<td>2 miss</td>
<td>1 miss</td>
<td>+3</td>
</tr>
<tr>
<td>( \phi ) efficiency</td>
<td></td>
<td></td>
<td>±9</td>
</tr>
<tr>
<td>subtotal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fit model( ( B^0 ) )</td>
<td></td>
<td></td>
<td>±6</td>
</tr>
<tr>
<td>Fit model( ( A_0^0 ) )</td>
<td></td>
<td></td>
<td>±8</td>
</tr>
<tr>
<td>( \frac{BR(\Lambda_c \to p\pi)}{BR(D^+ \to K\pi\pi)} )</td>
<td>0</td>
<td>±27%</td>
<td>±27%</td>
</tr>
</tbody>
</table>

Table 2: Systematic uncertainties for the \( A_0^0 \to A_c^\pm \pi^\pm \) BR measurement.

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7The \( B \to \pi\pi \) and \( B_s \to KK \) do in fact lie completely on top of each other.
The results are then:

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

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

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

<table>
<thead>
<tr>
<th>Effect</th>
<th>( \frac{BR(B_d \rightarrow \pi^+\pi^-)}{BR(B_d \rightarrow K^\pm\pi^\mp)} )</th>
<th>( A_{CP} (B_d \rightarrow 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><strong>0.055</strong></td>
<td><strong>0.017</strong></td>
</tr>
</tbody>
</table>

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

8 Conclusion

In conclusion, CDF has robust signals in the three channels: \( A^0_b \rightarrow A^{\pm}_s \pi^\mp \), \( B_s \rightarrow D^{\pm}_s \pi^\pm \), and \( B_s \rightarrow K^\pm K^\mp \). The first measurements of the \( B_s \rightarrow D^{\pm}_s \pi^\pm \), and \( A^0_b \rightarrow A^{\pm}_s \pi^\mp \) relative branching ratios have been made, and the the \( B_s \rightarrow K^\pm K^\mp \) signal is a first observation\(^8\). These constitute exciting first steps in the CDF programme for \( B^0_s \) and \( A^0_b \) physics.

References


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