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Hadronic B decays at BABAR

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Baryonic decays account for about 7% of the B-meson width, but are far less studied than decays into meson-only final states. We present recent BABAR results on the decays $B \to D^{(*)} p\bar{p}\ \mathrm{m}\cdot\pi$ with $\mathrm{m} = 0, 1, 2$, $B \to \Lambda_c^+ \bar{p}\pi^-\pi^+$ and $B^- \to \Sigma_c(2455)^{++}\bar{p}\pi^-\pi^-$. The results show a preference for high multiplicities for decays with a charmed baryon in the final state. Further, the decay dynamics show that resonant sub modes are a substantial contribution to the overall branching fraction.

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1. Introduction

From inclusive measurements it is known that $(6.8 \pm 0.6)\%$ of all B mesons decay into final states with baryons [1]. Using the large dataset of 470×10^6 $B\bar{B}$ pairs collected by the *BABAR* detector, it is possible to study these decays in detail. While the weak decay on the quark-level is well understood, the hadronisation processes into baryons plus mesons are largely unknown. Thus, investigating these decays can lead to a better understanding of the hadronisation into final states with a baryon-antibaryon pair.

2. Multiplicity hierarchy

Recently *BABAR* presented the measurement of 10 B-meson decays of the type $B \to D^{(*)} p\bar{p}\, \mathrm{m} \cdot \pi$ with $\mathrm{m} = 0, 1, 2$ [2]. The measured branching fractions, shown in Table 1, are all of the same order of magnitude but reveal a specific multiplicity hierarchy, where four-body decays have the largest branching fraction.

$$\mathscr{B}(B \to 3-\mathrm{body}) < \mathscr{B}(B \to 5-\mathrm{body}) < \mathscr{B}(B \to 4-\mathrm{body}) \tag{2.1}$$

decay mode	$\mathscr{B} \pm \sigma_{\mathrm{stat}} \pm \sigma_{\mathrm{syst}} (10^{-4})$
$\bar{B}^0 \to D^0 p\bar{p}$	$1.02 \pm 0.04 \pm 0.06$
$\bar{B}^0 \to D^{*0} p\bar{p}$	$0.97 \pm 0.07 \pm 0.09$
$\bar{B}^0 \to D^+ p\bar{p}\pi^-$	$3.32 \pm 0.10 \pm 0.29$
$\bar{B}^0 \to D^{*+} p\bar{p}\pi^-$	$4.55 \pm 0.16 \pm 0.39$
$B^- \to D^0 p\bar{p}\pi^-$	$3.72 \pm 0.11 \pm 0.25$
$B^- \to D^{*0} p\bar{p}\pi^-$	$3.73 \pm 0.17 \pm 0.27$
$\bar{B}^0 \to D^0 p\bar{p}\pi^-\pi^+$	$2.99 \pm 0.21 \pm 0.45$
$\bar{B}^0 \to D^{*0} p\bar{p}\pi^-\pi^+$	$1.91 \pm 0.36 \pm 0.29$
$B^- \to D^+ p\bar{p}\pi^-\pi^-$	$1.66 \pm 0.13 \pm 0.27$
$B^- \to D^{*+} p\bar{p}\pi^-\pi^-$	$1.86 \pm 0.16 \pm 0.19$

Table 1: Branching fraction results for $B \to D^{(*)} p\bar{p}\, \mathrm{m} \cdot \pi$ with $\mathrm{m} = 0, 1, 2$, ordered according to their multiplicity [2]. The first uncertainty is the statistical and the second the systematic uncertainty.

A similar comparison can be done for decays of the type $B \to \Lambda_c^+ \bar{p}\, \mathrm{m} \cdot \pi$. Table 2 gives the *BABAR* results on these decays [3, 4] and for $B^- \to \Lambda_c^+ \bar{p}\pi^-\pi^-\pi^+$ the corresponding CLEO result [5]. The results show a preference for high multiplicities, with the hierarchy given in eq. 2.2.

$$\mathscr{B}(B \to 2-body) < \mathscr{B}(B \to 3-body) < \mathscr{B}(B \to 4-body) < \mathscr{B}(B \to 5-body) \tag{2.2}$$

3. Decay dynamics

The analysis of $\bar{B}^0 \to \Lambda_c^+ \bar{p}\pi^-\pi^+$ shows a large contribution to the overall branching fraction from resonances as $\Sigma_c(2455)^{++}$, $\Sigma_c(2455)^0$, $\Sigma_c(2520)^{++}$ and $\Sigma_c(2520)^0$. The corresponding

decay mode	$\mathscr{B} \pm \sigma_{\text{stat}} \pm \sigma_{\text{syst}} \pm \sigma_{\mathscr{B}(\Lambda_c)} (10^{-4})$	reference
$\bar{B}^0 \to \Lambda_c^+ \bar{p}$	$0.19 \pm 0.02 \pm 0.01 \pm 0.05$	[3]
$\bar{B}^0 \to \Lambda_c^+ \bar{p} \pi^0$	$1.94 \pm 0.17 \pm 0.14 \pm 0.50$	[4]
$B^- \to \Lambda_c^+ \bar{p} \pi^-$	$3.38 \pm 0.12 \pm 0.12 \pm 0.88$	[3]
$\bar{B}^0 \to \Lambda_c^+ \bar{p} \pi^- \pi^+$	$12.25 \pm 0.47 \pm 0.73 \pm 3.19$	BABAR preliminary
$B^- \to \Lambda_c^+ \bar{p} \pi^- \pi^- \pi^+$	$22.5 \pm 2.5^{+2.4}_{-1.9} \pm 5.8$	[5]

Table 2: Branching fraction results for $B \to \Lambda_c^+ \bar{p}\, \mathrm{m} \cdot \pi$ with $\mathrm{m} = 0, 1, 2, 3$, ordered according to their multiplicity. The first uncertainty is the statistical, the second the systematic uncertainty and the third is due to the uncertainty on $\mathscr{B}(\Lambda_c^+ \to pK^-\pi^+)$.

branching fractions are given in Table 3 and the distributions of the invariant $\Lambda_c^+\pi^+$ and $\Lambda_c^+\pi^-$ mass distributions are shown in Figure 1. The $\Sigma_c(2520)$ is suppressed compared to the $\Sigma_c(2455)$ which can be explained by angular momentum conservation. The more surprising result is the relative suppression of the neutral Σ_c^0 compared to the double charged Σ_c^{++}. This suppression might

decay mode	$\mathscr{B} \pm \sigma_{\text{stat}} \pm \sigma_{\text{syst}} \pm \sigma_{\mathscr{B}(\Lambda_c)} (10^{-5})$
$\bar{B}^0 \to \Sigma_c(2455)^{++} \bar{p} \pi^-$	$21.31 \pm 0.97 \pm 0.98 \pm 5.54$
$\bar{B}^0 \to \Sigma_c(2455)^{0} \bar{p} \pi^+$	$9.06 \pm 065 \pm 0.42 \pm 2.36$
$\bar{B}^0 \to \Sigma_c(2520)^{++} \bar{p} \pi^-$	$11.52 \pm 0.97 \pm 0.54 \pm 2.99$
$\bar{B}^0 \to \Sigma_c(2520)^{0} \bar{p} \pi^+$	$2.21 \pm 0.69 \pm 0.10 \pm 0.57$

Table 3: Branching fraction results for $B \to \Sigma_c \bar{p} \pi$. The first uncertainty is the statistical, the second the systematic uncertainty and the third is due to the uncertainty on $\mathscr{B}(\Lambda_c^+ \to pK^-\pi^+)$.

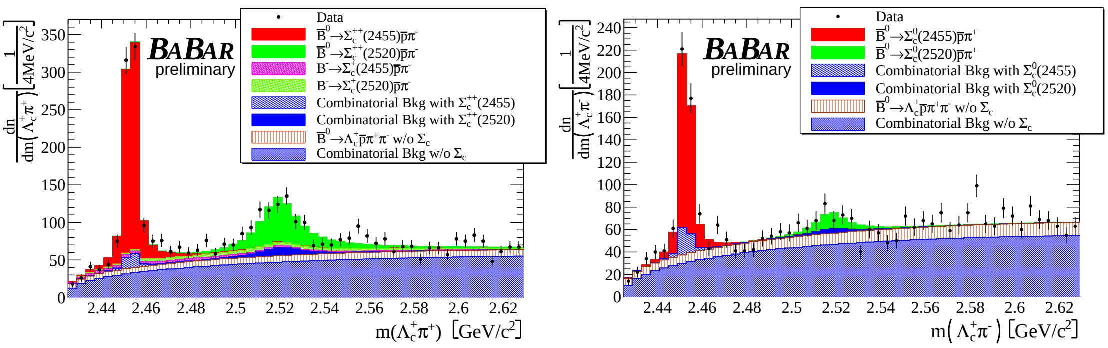

Figure 1: Invariant $\Lambda_c^+\pi^+$ (left) and $\Lambda_c^+\pi^-$ (right) mass distributions. Shown is a comparison of data (points) with different Monte Carlo background and signal sources.

be explained by different decay dynamics. A prominent difference can be seen in the invariant $\Sigma_c(2455)\bar{p}$ mass distribution for signal events, shown in Figure 2. Here, the signal events where selected by the $_s\mathcal{P}$lot algorithm [6] based on a fit in $m(\Lambda_c^+\pi^\pm)$. While the $m(\Sigma_c(2455)^{++}\bar{p})$ distribution is populated over the whole available phase space region the $m(\Sigma_c(2455)^0\bar{p})$ distribution is depopulated below 4.2 GeV$/c^2$. Furthermore, the $m(\Sigma_c(2455)^{++}\bar{p})$ distribution shows an enhancement at small invariant masses, compatible with the threshold enhancement seen in different

B decay modes [2, 3, 4, 7]. The explanation for the difference between the Σ_c^{++} and the Σ_c^0 comes quite naturally from pole models. For the decay $\bar{B}^0 \to \Sigma_c(2455)^{++}\bar{p}\pi^-$ a decay via an initial meson meson state M_1M_2 is possible, where one of the (virtual) mesons decays into $\Sigma_c^{++}\bar{p}$ (e.g. a virtual D^+), thus allowing for $m(\Sigma_c^{++}\bar{p})$ to be close to the threshold. In contrast no initial meson meson state is possible for $\bar{B}^0 \to \Sigma_c(2455)^0\bar{p}\pi^+$. Here, only baryon poles (e.g. via Δ^+ or $\Lambda_c(2595)^+$) are possible.

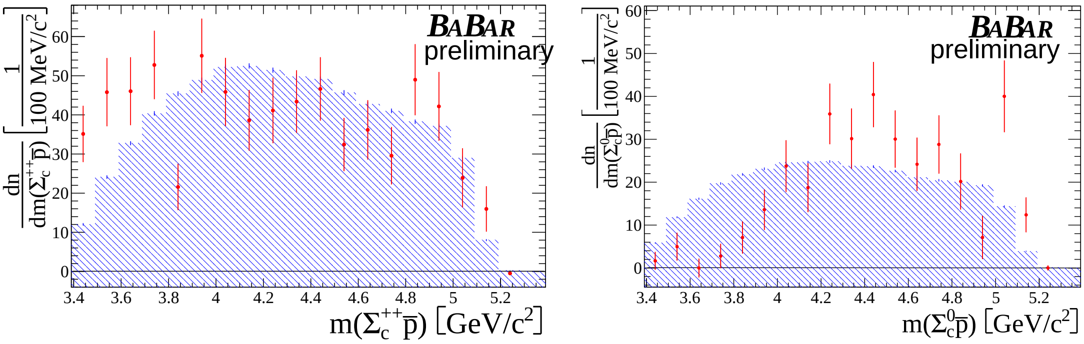

Figure 2: Invariant $\Sigma_c(2455)^{++}\bar{p}$ (left) and $\Sigma_c(2455)^0\bar{p}$ (right) mass distributions. Shown is a comparison of data (points) with a Monte Carlo phase space model (histogram), scaled to the same integral.

4. $B^- \to \Sigma_c(2455)^{++}\bar{p}\pi^-\pi^-$

The CLEO collaboration measured the branching fraction for $B^- \to \Lambda_c^+\bar{p}\pi^+\pi^-\pi^-$ [5], which is the largest known baryonic branching fraction up to date. Further, we have seen in the previous section that for the four body decay $\bar{B}^0 \to \Lambda_c^+\bar{p}\pi^-\pi^+$ a significant fraction of the events proceed via intermediate Σ_c states. A recent *BABAR* measurement shows that about 8% of the five body decay proceeds via the $\Sigma_c(2455)^{++}$ resonance [8]. The branching fraction for this resonant mode is

$$\mathscr{B}(B^- \to \Sigma_c(2455)^{++}\bar{p}\pi^-\pi^-) = (2.98 \pm 0.16_{\text{stat}} \pm 0.15_{\text{syst}} \pm 0.77_{\mathscr{B}(\Lambda_c)}) \times 10^{-4}. \quad (4.1)$$

A comparison with the branching fraction for $\bar{B}^0 \to \Sigma_c(2455)^{++}\bar{p}\pi^-$, given in Table 3 shows that the preference of higher multiplicities, as shown in section 2, is valid for decays via the $\Sigma_c(2455)^{++}$ as well. Studying the decay dynamics of this decay the efficiency corrected and sideband subtracted two body mass distributions, seen in Fig. 3, show deviations from the phase space expectation, determined by a Monte Carlo simulation. The $m(\bar{p}\pi^-)$ distribution shows deviations from phase space at low mass values, which are compatible with contributions from $\bar{\Delta}(1232, 1600, 1620)^{--}$. The $\bar{\Delta}(1600)^{--}$ region is not indicated in the Fig. 3 due to its large uncertainties on its mass and width. In the $m(\Sigma_c^{++}\pi^-)$ distribution a contribution from the $\Lambda_c(2595)^+$ resonance is apparent.

5. Summary

Comparing the multiplicity results for baryonic B decays with a charmed meson in the final state to those with a charmed baryon the branching fraction dependence of the multiplicity is evident. While for decays with a charmed meson the branching fractions are of the same order of

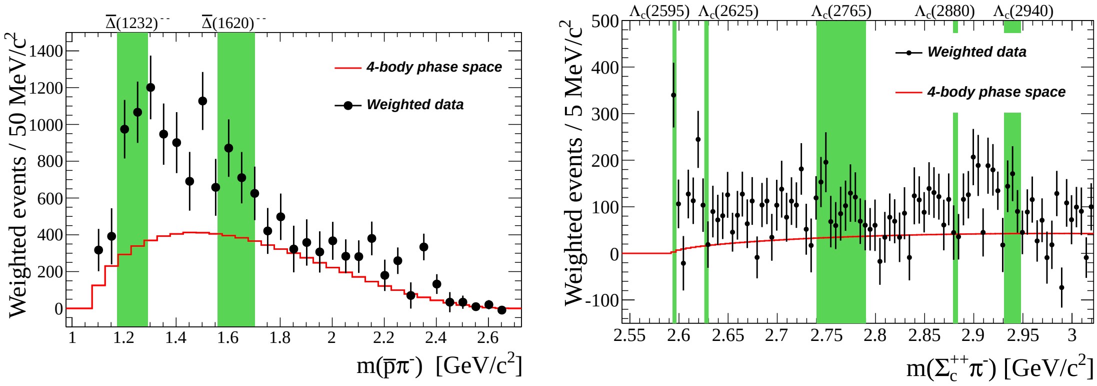

Figure 3: Invariant $\bar{p}\pi^-$ (left) and $\Sigma_c(2455)^{++}\pi^-$ (right) mass distributions. Shown is a comparison of data (points) with a Monte Carlo phase space model (histogram). The green shaded regions indicate represent possible resonances. The regions are centered at the average mass value and their width equals the natural width of the resonances.

magnitude with their maximum at a multiplicity of four, the branching fractions for B decays with a Λ_c increase by an order of magnitude with each additional meson in the final state. This feature can be explained in terms of the possible resonant substructure for these decays, increasing rapidly by adding a pion. Studying the resonant substructure *BaBar* results for $\bar{B}^0 \to \Lambda_c^+ \bar{p}\pi^-\pi^+$ indicate different decay dynamics depending on the charge of the intermediate Σ_c resonance. A phenomenological explanation for this difference comes from pole models.

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