

HADRONIC B AND D STUDIES AT BABAR

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We present new results on hadronic B and D decays from the BABAR experiment. The first part of this document presents searches for new channels which may be used for CP measurements. The second part is dedicated to hadronic decays with tests of QCD factorization predictions and other models for B structure and decay mechanisms. A new result on the reference branching ratio $D_s^+ \rightarrow \phi \pi^+$ is also reported.

1 CP related analysis

In this section, we present new CP violation related analysis of channels which could be used, in the future, to measure some of the CKM matrix parameters like $\gamma \equiv \arg \left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right]$ or a combination of γ and $\beta \equiv \arg \left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*} \right]$. To do this, one needs to measure CP asymmetries which are defined, for the $B \rightarrow f$ decay, as :

$$\mathcal{A}_{CP} = \frac{\mathcal{B}(B \rightarrow f) - \mathcal{B}(\bar{B} \rightarrow \bar{f})}{\mathcal{B}(B \rightarrow f) + \mathcal{B}(\bar{B} \rightarrow \bar{f})}$$

1.1 Measurement of the branching fraction and decay rate asymmetry of $B^- \rightarrow D_{\pi^+\pi^-\pi^0} K^-$

The decays $B \rightarrow D^{(*)0} K^{(*)-}$ can be used to measure the angle γ taking advantage of the interference between $b \rightarrow u\bar{c}s$ and $b \rightarrow c\bar{u}s$ decay amplitudes. Different approaches have been developed, and among which, γ measurements involving D decays to multi-body, using a Dalitz plot analysis technique as described in reference¹. In this analysis, we study the decay mode $B^- \rightarrow DK^-$ with the D -decay : $D \rightarrow \pi^+\pi^-\pi^0$ which is Cabibbo suppressed. This yields a much smaller event sample compared to Cabibbo allowed decay but its interfering D^0 and \bar{D}^0 amplitudes have similar magnitudes. Due to these interferences, the production rate might be

different from the product $\mathcal{B}_{prod} \equiv \mathcal{B}(B^- \rightarrow D^0 K^-) \times \mathcal{B}(D^0 \rightarrow \pi^+ \pi^- \pi^0) = (4.1 \pm 1.6) \times 10^{-6}$ (ref. ²). From a sample of 229 million of $B\bar{B}$ pairs, we found 133 ± 23 signal events which correspond to a branching ratio of $\mathcal{B}(B^- \rightarrow D_{\pi^+\pi^-\pi^0} K^-) = (5.5 \pm 1.0 \pm 0.7) \times 10^{-6}$. We determine the raw asymmetry and do not find any significant deviation from zero : $\mathcal{A}_{CP}^{raw} = 0.02 \pm 0.16 \pm 0.03$. The γ extraction needs a full Dalitz analysis of the D -decay.

1.2 Search for $B \rightarrow D_s^+ X_{light}$ with $X_{light} \equiv \pi^0, a_0^-, a_1^-$

The value of $\sin(2\beta + \gamma)$ can be extracted from the measurement of the time dependent CP asymmetry in $B \rightarrow D^- X_{light}^+$ decays with, for instance, $X_{light}^+ \equiv \pi^+, a_0^+, a_2^+$. In this case the asymmetry is given by : $\mathcal{A}_{CP}(\Delta t) = r \times \sin(2\beta + \gamma) \times \sin(\Delta m_d \Delta t)$ where $r = \mathcal{B}(B^0 \rightarrow D^+ X_{light}^-) / \mathcal{B}(B^0 \rightarrow D^- X_{light}^+)$. The decay $B^0 \rightarrow D^+ X_{light}^-$ is doubly Cabibbo suppressed and difficult to measure directly. Using $SU(3)$ flavor symmetry, it is possible to infer the value of $\mathcal{B}(B^0 \rightarrow D^+ X_{light}^-)$ from the value of $\mathcal{B}(B \rightarrow D_s^+ X_{light})$, the latter being less suppressed.

If $X_{light}^+ \equiv \pi^+$, then r is expected to be very small ($r \approx 0.02$) which implies a small asymmetry. In this case r might be deduced from the rate $\mathcal{B}(B^+ \rightarrow D_s^+ \pi^0)$. We measure this branching ratio from a sample of 124 millions of $B\bar{B}$ pair, we do not see any significant signal and quote an upper limit of : $\mathcal{B}(B^+ \rightarrow D_s^+ \pi^0) < 2.8 \times 10^{-5}$ in agreement with a previous measurement by CLEO ($< 2.4 \times 10^{-4}$ from ref. ²) and with the value of 0.9×10^{-5} expected from the rate of $\mathcal{B}(B^0 \rightarrow D_s^+ \pi^-)$ measured by Belle and BABAR experiments. If $X_{light}^+ \equiv a_0^+ (a_2^+)$, r might be quite large. This is due to the coupling constant of the W to the a_0 scalar meson (a_2 meson of spin 2) which is small and decreases the production rate of the Cabibbo allowed decay $B^0 \rightarrow D^- a_0^+ (a_2^+)$. The factorization hypothesis predicts a similar rate for Cabibbo allowed and Cabibbo suppressed decays ³ which results in $r \approx 1$. These decays are not yet in the reach of experiment (branching ratios around 10^{-6}), nevertheless, the theoretical predictions can be tested with the measurement of the branching ratio of the decay $B^0 \rightarrow D_s^+ a_0^- (a_2^-)$ expected at larger values : $\mathcal{B}(B^0 \rightarrow D_s^+ a_0^- (a_2^-)) \approx 7.5(1.5) \times 10^{-5}$ (ref. ^{3,4}). From a sample of 230 million of $B\bar{B}$ pairs, we measure these two branching ratios. The $a_0^- (a_2^-)$ is reconstructed in $a_{0,2}^- \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+$ which has a branching ratio of the order of 100 % (only 15 % for the a_2^- which lowers the experimental sensitivity). We do not find any significant signal and quote the upper limits : $\mathcal{B}(B^0 \rightarrow D_s^+ a_{0(2)}^-) < 4.0(25) \times 10^{-5}$ which shows a discrepancy of at least a factor two with the theoretical predictions.

1.3 Charmless decays

The decay $B^+ \rightarrow K^{*+}(\rightarrow K^+ \pi^0)\pi^0$ and its CP asymmetry is particularly interesting in light of the recent measurement of direct CP violation in the decay $B^0 \rightarrow K^+ \pi^-$ ⁵. From a sample of 232 million of $B\bar{B}$ pairs we find 88.5 ± 25.7 signal events which correspond to the branching ratio : $\mathcal{B}(B^+ \rightarrow K^{*+} \pi^0) = (6.9 \pm 2.0 \pm 1.3) \times 10^{-6}$ and do not find any hint of direct CP violation : $\mathcal{A}_{CP} = 0.04 \pm 0.29 \pm 0.05$ (reference ⁶).

Other types of charmless decays such as : $B \rightarrow \eta^{(\prime)} \pi, \rho, \omega, K$ are studied as well. These decays process via $b \rightarrow u$ CKM-suppressed trees and/or $b \rightarrow s$ penguins. They provide a good test of QCD factorization, may have large CP asymmetry and may provide sensitivity to the CKM angle γ . From a sample of 232 million of $B\bar{B}$ pairs, we measure the four branching ratios, and their asymmetries, and give two upper limits. Details on this analysis can be found in reference ⁷, no significant CP asymmetry is observed and measured branching ratios are in good agreement with theoretical predictions. We make the first observation of the decays $B^+ \rightarrow \eta' \pi^+$ and $B^+ \rightarrow \eta \rho^+$ and measure the corresponding decay rates : $\mathcal{B}(B^+ \rightarrow \eta' \pi^+) = (4.0 \pm 0.8 \pm 0.4) \times 10^{-6}$ and $\mathcal{B}(B^+ \rightarrow \eta \rho^+) = (8.4 \pm 1.9 \pm 1.1) \times 10^{-6}$.

2 Non CP related analysis

2.1 Measurement of the $B^0 \rightarrow D^{*-}D_s^{*+}$ and $D_s^+ \rightarrow \phi\pi^+$ branching ratios

We present measurements of the branching ratio $\mathcal{B}(B^0 \rightarrow D^{*-}D_s^{*+})$ which may lead to a precise determination of the reference $\mathcal{B}(D_s^+ \rightarrow \phi\pi^+)$. They have been performed on a sample of 123 million of $B\bar{B}$ pairs. The $B^0 \rightarrow D^{*-}D_s^{*+} \rightarrow (\bar{D}^0\pi^-)(D_s^+\gamma)$ decay is reconstructed using two different methods. The first one combines the fully reconstructed D^{*-} with the photon from the $D_s^{*+} \rightarrow D_s^+\gamma$ decay, without explicit reconstruction of the D_s^+ . To extract the number of partially reconstructed events, we compute the "missing mass" m_{miss} recoiling against the $D^{*-}\gamma$ system assuming that a $B^0 \rightarrow D^{*-}D_s^{*+} \rightarrow (\bar{D}^0\pi^-)(D_s^+\gamma)$ decay took place. For signal events, m_{miss} peaks at the D_s mass. We find, with this method, the following branching ratio : $\mathcal{B}_1 \equiv \mathcal{B}(B^0 \rightarrow D^{*-}D_s^{*+}) = (1.88 \pm 0.09 \pm 0.17) \%$ which is in agreement with the factorization model : $\mathcal{B}(B^0 \rightarrow D^{*-}D_s^{*+})_{theo} = (2.4 \pm 0.7) \%$. The second one is a full reconstruction technique of the decay chain $B^0 \rightarrow D^{*-}D_s^{*+}$ where the D_s candidate is reconstructed in the mode : $D_s^+ \rightarrow \phi\pi^+ \rightarrow (K^+K^-)\pi^+$. We measure with this method, the branching ratio $\mathcal{B}_2 \equiv \mathcal{B}(B^0 \rightarrow D^{*-}D_s^{*+}) \times \mathcal{B}(D_s^+ \rightarrow \phi\pi^+) = (8.81 \pm 0.86_{stat}) \times 10^{-4}$.

From the ratio $\mathcal{B}_2/\mathcal{B}_1$, where many systematics cancel out, we get a precise measurement of :

$$\mathcal{B}(D_s^+ \rightarrow \phi\pi^+) = (4.81 \pm 0.52 \pm 0.38) \%.$$

which represents an improvement on the error by about a factor of two over previous measurements². Details on this work can be found in the reference⁸.

2.2 Search for the rare decays $B^+ \rightarrow D^{(*)+}K^0$

This decay is expected to occur via a pure annihilation diagram. Such processes provide interesting insights into the internal dynamics of B mesons. This kind of diagram cannot be calculated in QCD factorization since both the quarks play a role. These amplitudes are expected to be suppressed, with respect to the amplitudes of spectator quark trees, by a factor $f_B/m_B \approx 0.04$ and have never been observed. Some studies⁹ indicate, though, that processes with a spectator quark can contribute to annihilation-mediated decays by *rescattering*. The branching ratio is expected to be either at the level of the current sensitivity (10^{-5}) if large rescattering occurs, or three orders of magnitude below if not⁹. We reconstruct the two decay modes $B^+ \rightarrow D^{*+}K_S^0$ and $B^+ \rightarrow D^+K_S^0$ within a sample of 226 million of $B\bar{B}$ pairs. We do not see any significant excess of signal and therefore we set the upper limits at 90 % CL : $\mathcal{B}(B^+ \rightarrow D^+K_S^0) < 0.5 \times 10^{-5}$ and $\mathcal{B}(B^+ \rightarrow D^{*+}K_S^0) < 0.9 \times 10^{-5}$.

2.3 Search for $B \rightarrow J/\psi D$ Decays

The spectra of the momentum of inclusive J/ψ mesons in the $\Upsilon(4S)$ rest frame observed by CLEO and by BABAR, compared with calculations using non-relativistic QCD (NRQCD), show an excess at low momentum, corresponding to a branching fraction of approximately 6×10^{-4} . Many hypothesis have been proposed to explain this result but no experimental evidence has been found to support them. The presence of $b\bar{u}c\bar{c}$ components (intrinsic charm) in the B -meson wave function has also been suggested to enhance the branching ratio of decays such as $B \rightarrow J/\psi \bar{D}(\pi)$ to the order of 10^{-4} while perturbative QCD predicts a branching ratio for $B \rightarrow J/\psi \bar{D}$ of 10^{-8} - 10^{-9} . We test the decay channels $B \rightarrow J/\psi D$ within a sample of 124 million of $B\bar{B}$ pairs. We do not find any evidence of signal and obtain upper limits of 1.3×10^{-5} for $B^0 \rightarrow J/\psi \bar{D}^0$ and 1.2×10^{-4} for $B^+ \rightarrow J/\psi D^+$ at 90 % CL. Therefore, we conclude that intrinsic charm is not supported as the explanation of low momentum J/ψ excess in B decays. More details on this analysis can be found in reference¹⁰.

2.4 Production and decay of the Ξ_c^0 at BABAR

We present a study of the Ξ_c^0 (csd) charmed baryon using a luminosity of 116.1 fb^{-1} through two decay modes : $\Xi_c^0 \rightarrow \Omega^- K^+$ and $\Xi_c^0 \rightarrow \Xi^- \pi^+$. First, we measure the ratio of these two decay rates to be $0.294 \pm 0.018 \pm 0.016$ which is compatible with the prediction, in a spectator quark model calculation, of 0.32. Then, we measure the p^* distribution of the Ξ_c^0 baryons, in the $\Upsilon(4S)$ frame, in order to study the production mechanisms in both $c\bar{c}$ and $B\bar{B}$ events. Results are shown on Figure 2.4. The double-peak structure seen in the p^* spectrum is due to two production mechanisms: the peak at lower p^* is due to Ξ_c^0 production in B meson decays and the peak at higher p^* is due to Ξ_c^0 production from the $c\bar{c}$ continuum. From these spectra we compute the cross-section of the production of Ξ_c^0 in continuum : $\sigma(e^+e^- \rightarrow c\bar{c} \rightarrow \Xi_c^0 X) \times \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+) = (388 \pm 39 \pm 41) \text{ fb}$ and the rate of Ξ_c^0 production in B decay : $\mathcal{B}(B \rightarrow \Xi_c^0 X) \times \mathcal{B}(\Xi_c^0 \rightarrow \Xi^- \pi^+) = (2.11 \pm 0.19 \pm 0.25) \times 10^{-4}$.

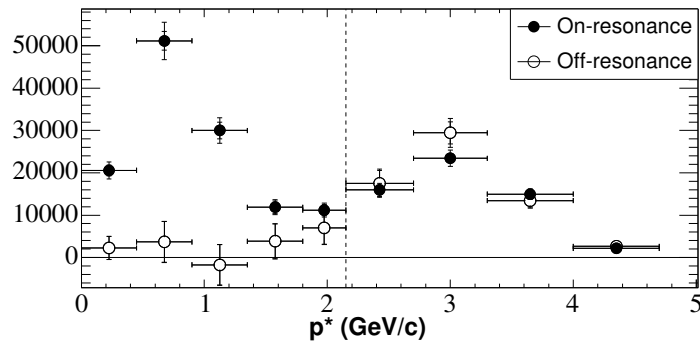


Figure 1: The p^* spectrum of Ξ_c^0 . Black dots represent on-peak data. Empty dots are off-resonance data ($e^+e^- \rightarrow u\bar{u}/d\bar{d}/s\bar{s}/c\bar{c}$ only) scaled to account for the difference in integrated luminosity and cross-section with on-peak data.

The high rate of Ξ_c^0 production at low p^* in B decays (below $1.2 \text{ GeV}/c$) is particularly intriguing, it implies that the invariant mass of the recoiling antibaryon system is typically above $2.0 \text{ GeV}/c^2$. This can be explained naturally by a substantial rate of charmed baryon pair production through the $b \rightarrow c\bar{c}s$ weak decay process which was observed indirectly in a previous BABAR analysis. Further details on this Ξ_c^0 production analysis can be found in reference ¹¹.

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