Hadronic $B$ Decays at $B_A^\perp A_B$

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Abstract. The large integrated luminosity collected by the $B_A^\perp A_B^\perp$ detector at the SLAC PEP-II $e^+e^- B$-Factory offers an excellent opportunity for the study of hadronic $B$-meson decays. A selection of recent results reported by $B_A^\perp A_B^\perp$ is presented: a full amplitude analysis of $B$ decays to the vector-vector final states $K\pi$, branching fraction measurements and study of decay dynamics in $B$ decays to proton-antiproton pairs and a light hadron, and branching fraction measurements of $B$ decays to the charmonium states $\eta_c$ and $h_c$ and $K$ or $K^*$ meson.

1. Introduction
The $B$-Factory experiments offer an excellent opportunity for hadronic $B$-decay studies. In fact they accumulated huge data samples, more than 470 fb$^{-1}$ in the case of $B_A^\perp A_B^\perp$. A selection of recent hadronic $B$-decay results by $B_A^\perp A_B^\perp$ is presented here. More results focused on measurements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix parameters and searches for physics beyond the Standard Model were presented in other talks at this Conference.

2. Amplitude Analysis of $B \to \phi K^*$ Decays
The $B$ decays to a two-vector final state like $\phi K^*(890)$ are characterized by three complex helicity amplitudes $A_\lambda$, with $\lambda = 0, +1$ and $-1$. For later convenience, we can also define $A_\pm = (A_0 \pm A_\perp)/\sqrt{2}$. In the Standard Model, the decay $B \to \phi K^*$ is a flavour-changing neutral current transition dominated by a $b \to s\bar{s}s$ penguin diagram. Owing to the V-A structure of the weak interaction, helicity conservation and spin flip suppression in penguin decays, one expects a hierarchy between the decay amplitudes of the three helicity states, namely $|A_0|^2 >> |A_\perp|^2 >> |A_\pm|^2$ [1].

Using a data sample of 384 million $B\bar{B}$ pairs, $B_A^\perp A_B^\perp$ performed a full amplitude analysis of the $B^+ \to \phi K^{**}(890)$ decay [6]. Charged conjugated modes are implied throughout. Analyzing the angular distributions of the decay, twelve non-trivial independent parameters are measured in an unbinned maximum likelihood fit. In the fit, different $B^+$ and $B^-$ amplitudes are also allowed to account for potential CP violation in the process. In contrast with the expectations, the fraction of longitudinal polarization, $f_L = |A_0|^2/\Sigma_\lambda |A_\lambda|^2$, is not found to be dominant: $0.49 \pm 0.05 \pm 0.03$. The fraction of transverse polarization, $f_\perp = |A_\perp|^2/\Sigma_\lambda |A_\lambda|^2$, is found to be $0.21 \pm 0.05 \pm 0.03$. The phases of the amplitudes, defined as $\phi_0 = \text{Arg}(A_{||}/A_0)$ and $\phi_\perp = \text{Arg}(A_{\perp}/A_0)$, can only be determined up to a two-fold ambiguity if no other information is used. In fact, two solutions would be equally plausible: one (I) with $\phi_\perp \sim \phi_{||} - \pi$ and $A_\perp \sim -A_{||}$ and consequently $|A_+|^2 << |A_-|^2$, the other (II) with $\phi_\perp \sim \phi_{||}$, $A_\perp \sim A_{||}$ and $|A_+|^2 >> |A_-|^2$. The ambiguity can be solved by using the dependence on the $K\pi$ invariant...
mass of the interference between the 1− and the 0+ Kπ components. Indeed about 57 events for 
B decays to φ(Kπ) with the Kπ pair in S wave are found by the fit. If the interference between 
the P wave K*(890) and S wave Kπ is taken into account, only solution II is acceptable.
This implies that |A+|^2 >> |A−|^2 and that the amplitudes for the 0 and + helicity states are 
comparable. The phases φI and φI are found to be π−0.67±0.20±0.07 and π−0.45±0.20±0.03, 
respectively. No sign of CP violation is observed.

BABAR also studied neutral B decays to φK0, including K+ states above the K*(890) [7].
Similarly to the charged K*(890) case, also in the neutral mode the fraction of longitudinal 
polarization is found to be not dominant, in contrast with expectations: fL = 0.51 ± 0.04 ± 0.02.
On the contrary, for the vector-tensor final state φK+ (1430), the fraction of longitudinal 
polarization is found to be larger, 0.85±0.06 ± 0.04.

In summary, an unexpected excess of the A+ amplitude is observed for B decays to 
φK*(890), confirming previous results by BABAR and Belle on B decays to φK* and ρK* [2].
Various hypotheses have been proposed to explain the excess of A+. Some of these comprise 
new mechanisms previously unaccounted for within the Standard Model, such as annihilation 
penguin [3] or electroweak penguin, or QCD rescattering [4]. Other hypotheses call for 
mechanisms beyond the Standard Model [5], such as scalar interaction or supersymmetry 
interaction.

3. Study of B → pph Decays

The study of B decays to final states of the form pph, where h indicates a light hadron, is 
interesting for the dynamical distribution of the three final state particles as well as for the 
possible presence of exotic intermediate states, such as the pentaquark candidate Θ+(1540) in 
the pKs0 spectrum or the fJ(2220) glueball candidate in the pp spectrum.

BABAR reported new results for h = π+, K+, K0, K* [8], while results for h = K+ were 
reported in [9]. The B+ → pphπ+ decay proceeds mainly through an external and internal W 
emission tree process; the B0 → pphK0(*) decay is dominated by a virtual loop penguin h → sg 
process; finally the decays B+ → pphK+(*) receive contributions from both the penguin and 
the doubly CKM suppressed external W emission tree process [10]. Since different mechanisms 
contribute, carrying in general different weak and strong phases, direct CP violation can occur in 
these processes [11]. Several experiments reported an enhancement at low pp masses in baryonic 
B and J/ψ decays [12]. This can be due to a short range correlation between p and p in a 
fragmentation chain, or to the decay of a resonance: the two scenarios can be distinguished by 
studying the distribution of events in the Dalitz plot [13].

Using a sample of about 232 million BB pairs, BABAR measured the branching fractions for 
the B → pph modes to be 3.0 ± 0.5 ± 0.3, 5.3 ± 1.5 ± 1.3, 1.5 ± 0.5 ± 0.4, 1.7 ± 0.3 ± 0.3, for 
h = K0, K*, K++, K++++, respectively, in units of 10−6. The results agree with the measurements 
reported by Belle [14]. In the case of B0 → pphK0, evidence of the decay is reported for the first 
time. It is interesting to compare the modes between one another, and with similar mesonic B 
decays. From isospin symmetry, one would expect the branching fraction for B0 → pphK0 to be 
comparable with that for B+ → pphK+, while it is found to be smaller by a factor about 2, 
in contrast with mesonic decays. This could possibly be explained by the absence of the tree 
diagram for pphK0, however if this diagram were important, it would be difficult to explain why 
pphπ+ is so suppressed. The branching fractions for B → pphK* are found to be consistently 
larger than B → pphK. The branching fraction for B+ → pphK++ is found to be larger than 
B0 → pphK0, similarly to the mesonic case.

No evidence is reported for the pentaquark candidate Θ+(1540) and the glueball candidate 
fJ(2220), and stringent upper limits on the branching fractions B(B0 → Θ+(1540)ρ) and 
B(B → fJ(2220)h) × B(fJ(2220) → pp) are derived. In the pp spectrum, signals for the ηc 
and J/ψ charmonium states are observed. In particular, the first evidence for the B+ → ηcK++
decay is reported. In the $pK^0$ and $pK^{*0}$ spectra, the $\Lambda^+_c$ baryon is observed. The branching fraction $B(B^0 \to \Lambda^+_c \bar{p})$ is measured to be $(21.0^{+6.7+6.7}_{-5.5-6.2} \pm 2.1_{-1.7-4.3}) \times 10^{-6}$, consistent with the measurement reported by Belle [15].

In the $ppK^0$ and $pp\pi^+$ final states, the low $p\bar{p}$ mass enhancement is found to be prominent, while no statistically relevant excess is observed in the case of $ppK^{*0}$. The distribution of events in the Dalitz plot is expected to be symmetric for a resonance [13]. In the $pp\pi^+$ case, there is a marginal excess at high $p\pi$ masses for $p\pi^+$ with respect to $p\pi^-$. However the low statistics does not allow to derive a definite conclusion.

**4. Branching Fraction Measurement for $B$ Decays to $\eta_cK^*$ and $\eta_cK^{(*)}\gamma$**

The study of $B$ decays to singlet states of charmonium, such as $\eta_c$ or $h_c$, is interesting because these are still more poorly known with respect to $B$ decays to triplet states, such as $J/\psi$ or $\chi_{c1}$. In addition, the $B$ decays to $P$ wave states, such as $h_c$ and the $\chi_{cJ}$ states, are foreseen in non-relativistic QCD [16] to occur with similar rates. $B$ decays to $\chi_{c0}$ or $\chi_{c1}$ and a kaon have indeed been observed with similar branching fractions, of around $10^{-4}$. However, no $B$ decay to $h_c$ has been observed yet: the Belle Collaboration reported an upper limit for $B^+ \to h_c K^+$ of $3.8 \times 10^{-5}$, at the 90% C.L. [17].

On a sample of about 384 million $B\bar{B}$ pairs, BABAR reported new measurements of the branching fractions for $B$ decays to $\eta_cK^{*0}$, $h_cK^+$ and $h_cK^{*0}$ [18]. The $\eta_c$ meson is reconstructed in the $K^0_S K^+\pi^-\pi^0$ and $K^+K^-\pi^0$ decay modes, and the $h_c$ in its decay to $\eta_c\gamma$, which is expected to comprise about half of the total decay width of $h_c$. A clear signal is observed for $B^0 \to \eta_cK^{*0}$ and its branching fraction is measured to be $(6.1 \pm 0.8 \pm 1.1) \times 10^{-4}$, reducing the uncertainty with respect to the previous world average by a factor about 2. No $h_c$ signal is seen and 90% C.L. upper limits are reported for the branching fraction products $B(B^+ \to h_c K^+) \times B(h_c \to \eta_c \gamma)$ and $B(B^0 \to h_c K^{*0}) \times B(h_c \to \eta_c \gamma)$ of $5.2 \times 10^{-5}$ and $2.41 \times 10^{-4}$, respectively, confirming $h_c$ suppression in $B$ decays.

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