Branching Fraction and CP Asymmetry Measurements in Inclusive $B \to X_s \ell^+ \ell^-$ and $B \to X_s \gamma$ Decays from BABAR

G. Eigen
representing the BABAR collaboration

Department of Physics, University of Bergen, Allegaten 55, N-5007 Bergen, Norway

Abstract

We present an update on total and partial branching fractions and on CP asymmetries in the semi-inclusive decay $B \to X_s \ell^+ \ell^-$. Further, we summarize our results on branching fractions and CP asymmetries for semi-inclusive and fully-inclusive $B \to X_s \gamma$ decays. We present the first result on the CP asymmetry difference of charged and neutral $B \to X_s \gamma$ decays yielding the first constraint on the ratio of Wilson coefficients $Im(C_8^{eff}/C_7^{eff})$.

Keywords: 1. Introduction

The decays $B \to X_s \gamma$ and $B \to X_s \ell^+ \ell^-$ are flavor-changing neutral current (FCNC) processes that are forbidden in the Standard Model (SM) at tree level. However, they can proceed via penguin loops and box diagrams. Figure 1 shows the lowest-order diagrams for both processes. The effective Hamiltonian factorizes short-distance effects represented by perturbatively-calculable Wilson coefficients ($C_i$) from long-distance effects specified by four-quark operators ($O_i$):

$$H_{eff} = \frac{G_F}{4\pi} \sum V_{sb}^* V_{td} C_i(\mu) O_i.$$ (1)

Here, $G_F$ is the Fermi constant, $V_{sb}$ and $V_{td}$ are CKM elements ($x = u, c, t$) and $\mu$ is the renormalization scale. The operators have to be calculated using non-perturbative methods, such as the heavy quark expansion [1, 2, 3, 4, 5, 6]. In $B \to X_s \gamma$, the dominant contribution arises from the magnetic dipole operator $O_7$ with a top quark in the loop. Thus, the branching fraction depends on the Wilson coefficient $C_7^{eff} = -0.304$ (NNLL) while the axial-vector part is specified by operator $O_{10}$ with Wilson coefficient $C_{10}^{eff} = -4.103$ (NNLL). Again, the top quark in the loop yields the most dominant contribution. New physics adds penguin and box diagrams with new particles modifying the SM values of the Wilson coefficients $Im(C_8^{eff}/C_7^{eff})$. New physics adds penguin and box diagrams with new particles modifying the SM values of the Wilson coefficients $Im(C_8^{eff}/C_7^{eff})$. 

Figure 1: Lowest-order diagrams for $B \to X_s \gamma$ (top) and $B \to X_s \ell^+ \ell^-$ (bottom).
cients. In addition, scalar and pseudoscalar couplings may contribute introducing new Wilson coefficients $C_S$ and $C_P$. Figure 2 shows examples of new physics processes involving a charged Higgs, a chargino and neutralinos $\tilde{g}, \tilde{\chi}^0$. These rare decays probe new physics at a scale of a few TeV.

![Figure 2: New physics processes with a charged Higgs bosons (left), a chargino plus up-type squarks (middle) and neutralinos plus down-type squarks (right).](image)

2. Study of $B \to X_s \ell^+ \ell^-$

Using a semi-inclusive approach, we have updated the partial and total branching fraction measurements of $B \to X_s \ell^+ \ell^-$ modes with the full BABAR data sample of $471 \times 10^6 BB$ events. We also perform the first measurement of direct CP asymmetry. For measuring partial and total branching fractions, we reconstruct 20 exclusive final states listed in Table 1. After accounting for $K^0_L$ modes, $K^0 \to \pi^0 \pi^0$ and $\pi^0$ Dalitz decays, they represent 70% of the inclusive rate for hadronic masses $m_{X_s} < 1.8$ GeV. Using JETSET fragmentation and theory predictions, we extrapolate for the missing modes and those with $m_{X_s} > 1.8$ GeV. We impose requirements on the beam-energy-substituted mass $m_{ES} = \sqrt{E^2_{CM} - p^2_B} > 5.225$ GeV and on the energy difference $-0.1 (0.05) < \Delta E = E^*_B - E_{CM}/2 < 0.05$ for $X_s \ e^+ e^-$ ($X_s \mu^+ \mu^-$) modes where $E^*_B$ and $p^*_B$ are $B$ momentum and $B$ energy in the center-of-mass (CM) frame and $E_{CM}$ is the total CM energy. We use no tagging of $B$ decay.

To suppress $e^+ e^- \to q \bar{q}$ ($q = u, d, s, c$) events and $BB$ combinatorial background, we define boosted decision trees (BDT) for each $q^2$ bin in $e^+ e^-$ and $\mu^+ \mu^-$ separately (see Table 2). From these BDTs, we determine a likelihood ratio ($L_R$) to separate signal from $q \bar{q}$ and $BB$ backgrounds. We veto $J/\psi$ and $\psi(2S)$ mass regions and use them as control samples. Figures 3 and 4 show the $m_{ES}$ and $L_R$ distributions for $e^+ e^-$ modes in bin $q_5$ and for $\mu^+ \mu^-$ modes in bin $q_1$, respectively.

We measure $d \Sigma(B \to X_s \ell^+ \ell^-)/dq^2$ in six bins of $q^2 = m_{ES}^2$ and four bins of $m_{X_s}$ defined in Table 2. We extract the signal in each bin from a two-dimensional fit to $m_{ES}$ and $L_R$. Figure 5 shows the differential branching fraction as a function of $q^2$ (top) and $m_{X_s}$ (bottom) [15].

### Table 1: Exclusive modes used in the semi-inclusive $B \to X_s \ell^+ \ell^-$ analysis.

| Mode                      | Mode                      |
|---------------------------|---------------------------|
| $B^+ \to K^0 \mu^+ \mu^-$ | $B^+ \to K^- e^+ e^-$     |
| $B^+ \to K^0 e^+ e^-$      | $B^- \to K^+ \mu^+ \mu^-$ |
| $B^0 \to K^0 (K^0 \pi^0)_{\mu^+ \mu^-}$ | $B^0 \to K^+ (K^+ \pi^0)_{\mu^+ \mu^-}$ |
| $B^0 \to K^0 (K^0 \pi^0)_{e^+ e^-}$ | $B^0 \to K^- (K^- \pi^0)_{e^+ e^-}$     |
| $B^0 \to K^0 (K^0 \pi^0)_{e^+ e^-}$ | $B^0 \to K^- (K^- \pi^0)_{e^+ e^-}$     |
| $B^0 \to K^0 (K^0 \pi^0)_{e^+ e^-}$ | $B^0 \to K^- (K^- \pi^0)_{e^+ e^-}$     |

### Table 2: Definition of the $q^2$ bins.

| $q^2$ bin | $q^2$ range [GeV$^2$/c$^4$] | $m_{\ell\ell}$ range [GeV] | $m_{X_s}$ bin |
|-----------|----------------------------|-----------------------------|---------------|
| 0         | $1.0 < q^2 < 6.0$          | $1.00 < m_{\ell\ell} < 2.45$ | 1             |
| 1         | $0.1 < q^2 < 2.0$          | $0.32 < m_{\ell\ell} < 1.41$ | 2             |
| 2         | $2.0 < q^2 < 4.3$          | $1.41 < m_{\ell\ell} < 2.07$ | 3             |
| 3         | $4.3 < q^2 < 8.1$          | $2.07 < m_{\ell\ell} < 2.6$  | 4             |
| 4         | $10.1 < q^2 < 12.9$        | $3.18 < m_{\ell\ell} < 3.59$ | 5             |
| 5         | $14.2 < q^2 < (m_{B} - m_{X_s})^2$ | $3.77 < m_{\ell\ell} < (m_{B} - m_{X_s})^2$ | 6             |

![Figure 3: Distributions of $m_{ES}$ (left) and likelihood ratio (right) for $B \to X_s \ell^+ \ell^-$ in $q^2$ bin $q_5$ showing data (points with error bars), the total fit (thick solid blue curves), signal component (red peaking curves), signal cross feed (cyan/grey curves), $BB$ background (magenta/dark grey smooth curve), $e^+ e^- \to q \bar{q}$ background (green/grey curves) and charmonium background (yellow/light grey curves).](image)
Table 1 summarizes the differential branching fractions in the low and high $q^2$ regions in comparison to the SM predictions [17] [18] [19] [20] [21] [22] [23] [24] [25] [26] [27]. In both regions of $q^2$, the differential branching fraction is in good agreement with the SM prediction. These results supersede the previous BABAR measurements [28] and are in good agreement with the Belle results [29].

The direct CP asymmetry is defined by:

$$A_{CP} = \frac{B(\bar{B} \to \bar{X}_s \ell^+ \ell^-) - B(B \to X_s \ell^+ \ell^-)}{B(\bar{B} \to \bar{X}_s \ell^+ \ell^-) + B(B \to X_s \ell^+ \ell^-)}$$

We use 14 self-tagging modes consisting of all $B^+$ modes and the $B^0$ modes with decays to a $K^+$ listed in Table 1 to measure $A_{CP}(B \to X_s \ell^+ \ell^-)$ in five $q^2$ bins. Note that we have combined bins $q_1$ and $q_2$ due to low statistics. Figure 6 shows the CP asymmetry as a function of $q^2$. The SM prediction of the CP asymmetry in the entire $q^2$ region is close to zero [30] [31] [32] [8]. In new physics models, however, $A_{CP}$ may be significantly enhanced [11] [33]. In the full range of $q^2$ we measure $A_{CP} = 0.04 \pm 0.11 \pm 0.01$ [16], which is in good agreement with the SM prediction. The CP asymmetries in the five $q^2$ bins are also consistent with zero.

Figure 4: Distributions of $m_{Xs}$ (left) and likelihood ratio (right) for $B \to X_s \mu^+ \mu^-$ in $q^2$ bin $q_4$ showing data (points with error bars), the total fit (thick solid blue curves), signal component (red peaking curves), signal cross feed (cyan/grey curves), $B \bar{B}$ background (magenta/dark grey smooth curve), $e^+e^- \to q \bar{q}$ background (green/grey curves) and charmonium background (yellow/light grey curves).

Figure 5: Differential branching fraction of $B \to X_s e^+ e^-$ (blue points), $B \to X_s \mu^+ \mu^-$ (black squares), and $B \to X_s \ell^+ \ell^-$ (red triangles) versus $q^2$ (top) and versus $m_{Xs}$ (bottom) in comparison to the SM prediction (histogram). The grey-shaded bands show the $J/\psi$ and $\psi(2S)$ vetoed regions.

Figure 6: The CP asymmetry as a function of $q^2$. The grey-shaded bands show the $J/\psi$ and $\psi(2S)$ vetoed regions.
3. Study of $B \to X_{\gamma} \gamma$

In the SM, the $B \to X_{\gamma} \gamma$ branching fraction is calculated in next-to-next leading order (4 loops) yielding

$$\mathcal{B}(B \to X_{\gamma} \gamma) = (3.15 \pm 0.23) \times 10^{-4}$$  \hspace{1cm} (3)$$

for photon energies $E_\gamma > 1.6$ GeV \([34, 34]\).

To extract the $B \to X_{\gamma} \gamma$ signal experimentally from $e^+e^- \to B\bar{B}$ and $e^+e^- \to q\bar{q}$ backgrounds, we use two very different strategies. The first strategy consists of a semi-inclusive approach in which we sum over 38 exclusive $B \to X_{\gamma} \gamma$ final states with $1K^\pm(1K^0)$ or $3K^\pm$, $\leq 4\pi(\leq 2\pi)$, and $\leq 1\eta$. We use no tagging of the other $B$ meson. We need to model the missing modes. Due to large backgrounds, we select events with a minimum photon energy of $E_\gamma > 1.9$ GeV and then extrapolate the branching fraction to photon energies $E_\gamma > 1.6$ GeV. With this approach, we measure the branching fraction, $CP$ asymmetry and the difference in $CP$ asymmetries between charged and neutral $B$ decays using $471 \times 10^6 B\bar{B}$ events \([36]\).

The second strategy is a fully inclusive approach. To suppress backgrounds from $B\bar{B}$ and $q\bar{q}$ decays, we impose stringent constraints on isolated photons to remove clusters that may have originated from $\nu\tau$ and $\eta$ decays. We use a semileptonic tag of the other $B$ meson and require a minimum photon energy of $E_\gamma > 1.8$ GeV but impose no requirements on the hadronic mass system. Using $383 \times 10^6 B\bar{B}$ events, we measure the $B \to X_{\gamma} \gamma$ branching fraction measurement and the $CP$ asymmetry for $B \to X_{\gamma} \gamma$ \([37, 38]\).

Table 4 summarizes our $B \to X_{\gamma} \gamma$ branching fraction measurements of the semi-inclusive and fully inclusive methods \([36, 37, 38]\). Figure 7 shows the BABAR results extrapolated to a minimum photon energy of $1.6$ GeV in comparison to results from Belle \([40, 41, 42]\), CLEO \([43]\) and the SM prediction \([34, 35]\). Our results are in good agreement with those of the other experiments as well as the SM prediction.

For the semi-inclusive method, the direct $CP$ asymmetry is defined by:

$$\mathcal{A}_{CP}(X_{\gamma}) = \frac{\mathcal{B}(\bar{B} \to \bar{X}_{\gamma} \gamma) - \mathcal{B}(B \to X_{\gamma} \gamma)}{\mathcal{B}(\bar{B} \to \bar{X}_{\gamma} \gamma) + \mathcal{B}(B \to X_{\gamma} \gamma)}$$  \hspace{1cm} (4)$$

The SM prediction yields $-0.6% < \mathcal{A}_{CP}(B \to X_{\gamma} \gamma) < 2.8%$ \([45, 46]\). Using 16 self-tagging exclusive modes and $471 \times 10^6 B\bar{B}$ events, we measure $\mathcal{A}_{CP}(B \to X_{\gamma} \gamma) = (1.7 \pm 1.9_{stat} \pm 1.0_{syst})%$ \([47]\). This supersedes the old BABAR measurement \([48]\). We further measures the $CP$ asymmetry difference between charged and neutral $B$ decays:

$$\Delta \mathcal{A}_{CP} = \mathcal{A}_{CP}(B^+ \to X_{\gamma}^+ \gamma) - \mathcal{A}_{CP}(B^0 \to X_{\gamma}^0 \gamma)$$  \hspace{1cm} (5)$$

which depends on the Wilson coefficients $C_7^{eff}$ and $C_{eff}^{eff}$:

$$\Delta \mathcal{A}_{CP} = 4\pi^2 \xi_s \frac{\Lambda_{\gamma8}}{m_6} Im \frac{C_{eff}^{C_7}}{C_{eff}^{C_7}} \approx 0.12 - \frac{\Lambda_{\gamma8}}{100 \text{MeV}} Im \frac{C_{eff}^{C_7}}{C_{eff}^{C_7}}$$  \hspace{1cm} (6)$$

where the scale parameter $\Lambda_{\gamma8}$ is constrained by 17 MeV $< \Lambda_{\gamma8} < 190$ MeV. In the SM, $C_7^{eff}$ and $C_{eff}^{eff}$ are real so that $\Delta \mathcal{A}_{CP}$ vanishes. However in new physics models, these Wilson coefficients may have imaginary parts yielding a non-vanishing $\Delta \mathcal{A}_{CP}$.

From a simultaneous fit to charged and neutral $B$ decays, we measure $\Delta \mathcal{A}_{CP}(B \to X_{\gamma} \gamma) = (5.0 \pm 3.9_{stat} \pm 1.5_{syst})%$ from which we set an upper and lower limit at 90% CL on $Im(C_{eff}^{C_7}/C_{eff}^{C_7})$ \([47]\):

$$-1.64 < Im \frac{C_{eff}^{C_7}/C_{eff}^{C_7}}{C_{eff}^{C_7}} < 6.52 \text{ at 90% CL.}$$  \hspace{1cm} (7)$$

This is the first $\Delta \mathcal{A}_{CP}$ measurements and the first constraint on $Im(C_{eff}^{C_7}/C_{eff}^{C_7})$. Figure 8 (top) shows the $\Delta \chi^2$ of
the fit as a function of \( \text{Im}(C_{7}^{\text{eff}}/C_{7}^{\text{eff}}) \). The shape of \( \Delta \chi^2 \) as a function of \( \text{Im}(C_{8}^{\text{eff}}/C_{7}^{\text{eff}}) \) is not parabolic indicating that the likelihood has a non-Gaussian shape. The reason is that \( \Delta \chi^2 \) is determined from all possible values of \( \hat{\Lambda}_{78} \). In the region \( \sim 0.2 < \text{Im}(C_{8}^{\text{eff}}/C_{7}^{\text{eff}}) < 2.6 \) a change in \( \text{Im}(C_{8}^{\text{eff}}/C_{7}^{\text{eff}}) \) \( \Delta \chi^2 \) can be compensated by a change in \( \hat{\Lambda}_{78} \) leaving \( \Delta \chi^2 \) unchanged. For positive values larger (smaller) than 2.6 (0.2), \( \Delta \chi^2 \) increases slowly (rapidly), since \( \hat{\Lambda}_{78} \) remains nearly constant at the minimum value (increases rapidly). For negative \( \text{Im}(C_{8}^{\text{eff}}/C_{7}^{\text{eff}}) \) values, \( \hat{\Lambda}_{78} \) starts to decrease again, which leads to a change in the \( \Delta \chi^2 \) shape. Figure 8 (bottom) shows \( \hat{\Lambda}_{78} \) as a function of \( \text{Im}(C_{8}^{\text{eff}}/C_{7}^{\text{eff}}) \).

In the fully-inclusive analysis, the \( B \to X_{d} \) decay cannot be separated from the \( B \to X_{s} \) decay and we measure:

\[
\mathcal{A}_{CP}(X_{s,d}Y) = \frac{\mathcal{B}(\bar{B} \to \bar{X}_{s,d}Y) - \mathcal{B}(B \to X_{s,d}Y)}{\mathcal{B}(B \to \bar{X}_{s,d}Y) + \mathcal{B}(B \to X_{s,d}Y)}. \tag{8}
\]

In the SM, \( \mathcal{A}_{CP}(B \to X_{s,d}Y) \) is zero \cite{49}. From the charge of the \( B \) and \( \bar{B} \), we determine the \( CP \) asymmetry. Using \( 383 \times 10^{6} \) \( BB \) events, we measure \( \mathcal{A}_{CP}(B \to X_{s,d}Y) = (5.7 \pm 6.0 \pm 1.8)\% \), which is consistent with the SM prediction \cite{49}. Figure 9 shows a summary of all \( CP \) asymmetry measurements in comparison to the SM predictions.

![Figure 8: The \( \Delta \chi^2 \) function versus \( \text{Im}(C_{8}^{\text{eff}}/C_{7}^{\text{eff}}) \) (top) and the dependence of \( \hat{\Lambda}_{78} \) on \( \text{Im}(C_{8}^{\text{eff}}/C_{7}^{\text{eff}}) \) (bottom). The blue dark-shaded (orange light-shaded) regions show the 68\% (90\%) CL intervals.](image)

![Figure 9: Summary of \( \mathcal{A}_{CP} \) measurements for \( B \to X_{s,d}Y \) from semi-inclusive analyses (BABAR \cite{27}, Belle \cite{50}) and for \( B \to X_{s,d}Y \) from fully inclusive analyses (BABAR \cite{37, 38, 39}, CLEO \cite{51}, Belle \cite{52} and the HFAG average \cite{44}) in comparison to the SM prediction for \( B \to X_{s,d}Y \) \cite{45, 50, 49}.](image)

4. Conclusion

We performed the first \( \mathcal{A}_{CP} \) measurement in five \( q^{2} \) bins in semi-inclusive \( B \to X_{s,d}e\ell \gamma \) decays and updated the differential branching fraction. The \( B \to X_{s,d}e\ell \gamma \) partial branching fractions and \( CP \) asymmetries are in good agreement with the SM predictions. Our \( \mathcal{A}_{CP} \) measurement in the semi-inclusive \( B \to X_{s,d}Y \) decay is the most precise \( CP \) asymmetry measurement. The \( \Delta \mathcal{A}_{CP}(B \to X_{s,d}Y) \) result yields first constraint on \( \text{Im}(C_{8}^{\text{eff}}/C_{7}^{\text{eff}}) \). The \( B \to X_{s,d} \) branching fractions and \( CP \) asymmetries are both in good agreement with the SM predictions. New progress on these inclusive decays will come from Belle II. For the \( B \to X_{s,d}Y \) and \( B \to X_{s,d}e\ell \gamma \) semi-inclusive decays, we expect precision measurements. For the inclusive \( B \to X_{s,d}Y \) and \( B \to X_{s,d}e\ell \gamma \) decays, we expect new possibilities by tagging the other \( B \) meson via full \( B \) reconstruction.
5. Acknowledgments

This work was supported by the Norwegian Research Council. I would like to thank members of the BABAR collaboration for giving me the opportunity to present these results. In particular, I would like to thank Doug Roberts, Liang Sun and David Hitlin for their fruitful suggestions.

References

[1] K. G. Wilson, Phys. Rev. 179, 1499 (1969).
[2] K. G. Wilson and J. B. Kogut, Phys. Rept. 12, 75 (1974).
[3] N. Isgur, D. Scora, B. Grinstein and M. B. Wise, Phys. Rev. D 39, 790 (1989).
[4] N. Isgur and M. B. Wise, Phys. Lett. B 232, 113 (1989).
[5] H. Georgi, Phys. Lett. B 240, 447 (1990).
[6] B. Grinstein and D. Pirjol, Phys. Rev. D 70, 114005 (2004) [hep-ph/0404250].
[7] G. Buchalla, A. J. Buras and M. E. Lautenbacher, Rev. Mod. Phys. 70, 1125 (1998) [hep-ph/9812350].
[8] W. Altmannshofer, P. Ball, A. Bharucha, A. J. Buras, D. M. Straub and M. Wick, JHEP 0901, 019 (2009) [arXiv:0811.1214 [hep-ph]].
[9] A. Ali, E. Lunghi, C. Greub and G. Hiller, Phys. Rev. D 66, 034002 (2002) [hep-ph/0112300].
[10] C. Bobeth, P. Gambino, M. Gorbahn and U. Haisch, JHEP 0404, 017 (2004) [hep-ph/0311087].
[11] S. Bobeth, P. Gambino, M. Gorbahn and U. Haisch, JHEP 0404, 071 (2004) [hep-ph/0312090].
[12] A. Ghinculov, T. Hurth, G. Isidori and Y. P. Yao, Nucl. Phys. B 685, 351 (2004) [hep-ph/0312128].
[13] C. Greub, V. Pilipp and C. Schüpbach, JHEP 0812, 045 (2008) [arXiv:0804.3877 [hep-ph]].
[14] T. Huber, T. Hurth and E. Lunghi, Nucl. Phys. B 702, 40 (2008) [arXiv:0712.2009 [hep-ph]].
[15] T. Huber, E. Lunghi, M. Misiak and D. Wyler, Nucl. Phys. B 740, 105 (2006) [hep-ph/0512066].
[16] M. Beneke, G. Buchalla, M. Neubert and C. T. Sachrajda, Eur. Phys. J. C 61, 439 (2009) [arXiv:0902.4446 [hep-ph]].
[17] B. Aubert et al. [BaBar Collaboration], Phys. Rev. D 93, 081102 (2004) [hep-ex/0404006].
[18] M. Iwasaki et al. [Belle Collaboration], Phys. Rev. D 79, 021106 (2009) [hep-ex/0803040].
[19] D. S. Du and M. Z. Yang, Phys. Rev. D 54, 882 (1996) [hep-ph/9510267].
[20] A. Ali and G. Hiller, Eur. Phys. J. C 8, 619 (1999) [hep-ph/9812267].
[21] C. Bobeth, G. Hiller and G. Piranishvili, JHEP 0807, 106 (2008) [arXiv:0805.2925 [hep-ph]].
[22] A. K. Alok, A. Dhoge and S. Ray, Phys. Rev. D 79, 034017 (2009) [arXiv:0811.1186 [hep-ph]].
[23] M. Misiak, H. M. Asatiani, K. Bieri, M. Czakon, A. Czarnecki, T. Ewerth, A. Ferroglia and P. Gamberg et al., Phys. Lett. B 664, 206 (2007) [hep-ph/0609241].
[24] M. Misiak and M. Steinhauser, Nucl. Phys. B 764, 62 (2007) [hep-ph/0609241].
[25] J. P. Lees et al. [BaBar Collaboration], Phys. Rev. D 86, 052012 (2012) [arXiv:1207.2520 [hep-ex]].
[26] J. P. Lees et al. [BaBar Collaboration], Phys. Rev. Lett. 109, 191801 (2012) [arXiv:1207.2500 [hep-ex]].
[27] J. P. Lees et al. [BaBar Collaboration], Phys. Rev. D 86, 112008 (2012) [arXiv:1207.5772 [hep-ex]].
[28] B. Aubert et al. [BaBar Collaboration], Phys. Rev. D 77, 051103 (2008) [arXiv:0711.4889 [hep-ex]].
[29] K. Abe et al. [Belle Collaboration], Phys. Lett. B 511, 151 (2001) [hep-ex/0102042].
[30] A. Limosani et al. [Belle Collaboration], Phys. Rev. Lett. 103, 241801 (2009) [arXiv:0907.1384 [hep-ex]].
[31] T. Saito et al. [Belle Collaboration], Talk at Moriond Electroweak 2014.
[32] S. Chen et al. [CLEO Collaboration], Phys. Rev. Lett. 87, 251807 (2001) [hep-ex/0108032].
[33] D. Asner et al. [Heavy Flavor Averaging Group Collaboration], arXiv:1010.1589 [hep-ex].
[34] A. L. Kagan and M. Neubert, Phys. Rev. D 58, 094012 (1998) [hep-ph/9803368].
[35] M. Benzke, S. J. Lee, M. Neubert and G. Paz, Phys. Rev. Lett. 106, 141801 (2011) [arXiv:1012.3167 [hep-ph]].
[36] J. P. Lees et al. [BaBar Collaboration], arXiv:1406.0534 [hep-ex].
[37] B. Aubert et al. [BaBar Collaboration], Phys. Rev. Lett. 101, 171804 (2008) [arXiv:0805.4796 [hep-ex]].
[38] T. Hurth, E. Lunghi and W. Porod, Nucl. Phys. B 704, 56 (2005) [hep-ph/0412250].
[39] S. Ishida et al. [Belle Collaboration], Phys. Rev. Lett. 93, 031803 (2004) [hep-ex/0308038].
[40] T. E. Coan et al. [CLEO Collaboration], Phys. Rev. Lett. 86, 5661 (2001) [hep-ex/0010075].
[41] L. Pesanet et al. [Belle Collaboration], talk at DIS14, arXiv:1406.6356 [hep-ex].