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Recent results on charmless B meson decays from Babar

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Recent results from the Babar experiment at the PEP-II asymmetric-energy e^+e^- collider at SLAC concerning charmless B meson decays are presented. Specifically, the first evidence for the $B \to \omega\omega$ decay mode, and a study of the CP asymmetry as a function of the K^+K^- invariant mass in $B^+ \to K^+K^-K^+$ events, are discussed.

XV International Conference on Hadron Spectroscopy-Hadron 2013
4-8 November 2013
Nara, Japan

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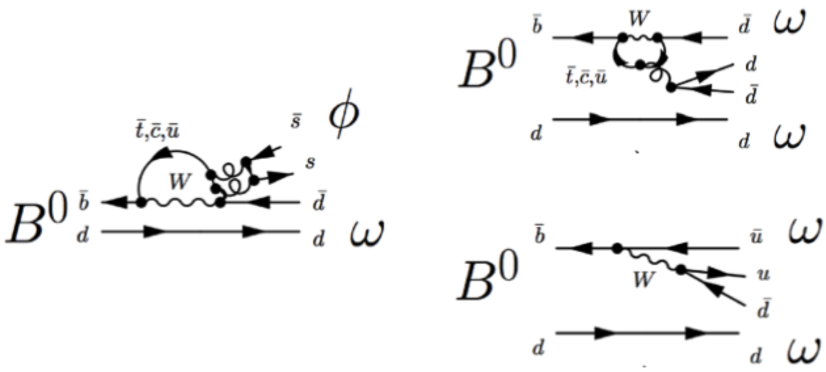

Figure 1: Diagrams for (left) $B \to \omega\phi$ and (right) $B \to \omega\omega$ decays.

1. Introduction

The Babar experiment operated at the PEP-II asymmetric-energy e^+e^- collider at SLAC from 1999 to 2008. The data analysis is still very active, with around 30 physics publications expected in 2013. This contribution reports on two recent studies of charmless B meson decays. One, a search for $B \to \omega\omega$ and $B \to \omega\phi$ decays, will soon be submitted for publication. The other, a study of the $m_{K^+K^-}$ mass dependence of the CP asymmetry in $B^+ \to K^+K^-K^+$ events, is available as arXiv:1305.4218 (2013) and is a reinterpretation of results published in PRD85, 112010 (2012).

All results presented are preliminary.

2. Search for $B \to \omega\omega$ and $B \to \omega\phi$ decays

The $B \to \omega\omega$ and $B \to \omega\phi$ decay modes both represent vector-vector (VV) decays of B mesons. Diagrams are shown in Fig. 1. $B \to \omega\phi$ is a pure $b \to d$ penguin process, which is a relatively unstudied quark transition. It is one of the few $b \to d$ transitions that is sensitive to electroweak amplitudes, as discussed in Ref. [1]. The standard model branching fraction is expected to be small: in the range $(0.01 - 0.2) \times 10^{-6}$. The $B \to \omega\omega$ process proceeds through both tree and penguin diagrams and has a predicted standard model branching fraction of around $(0.5 - 3) \times 10^{-6}$. Observed rates or upper limits on these branching fractions provide information on $B \to VV$ loop diagrams; deviations from standard model expectations are potential signals for new physics. Through SU(3) relations, measurements of the branching fractions for these two processes can be used to constrain amplitudes in other vector-vector processes, such as $B \to \phi K^*$, and potentially help to address possible anomalies seen in penguin vector-vector decays, such as the low value of the longitudinal polarization fraction in $B \to \phi K^*$ decays.

Previous results on $B \to \omega\omega$ and $B \to \omega\phi$ decays have been presented by the CLEO [2] and Babar [3] Collaborations. CLEO, with a data sample of around 3.3×10^6 events, set limits of about 2×10^{-5} on both branching fractions [90% confidence level (CL)]. Babar, with a data sample of 233×10^6 events, improved these limits to 4.0×10^6 for $B \to \omega\omega$ and 1.2×10^{-6} for $B \to \omega\phi$ (90% CL). Babar observed an indication of an $\omega\omega$ signal at the level of 2.2 standard deviations. The result in Ref. [3] was based on around half the final Babar dataset.

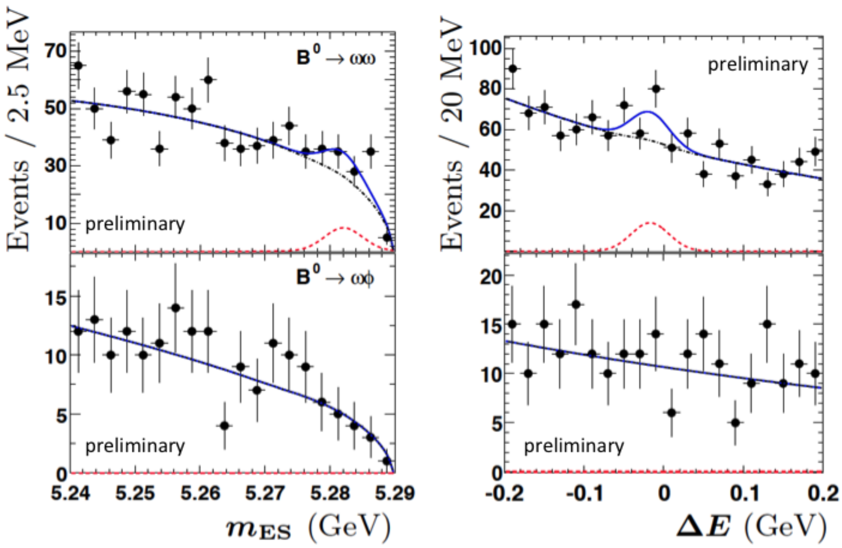

Figure 2: Projections of the results of the maximum likelihood fit on (left) m_{ES} and (right) ΔE for (top) $B \to \omega\omega$ and (bottom) $B \to \omega\phi$ decays, in comparison to data. The dashed (red) curves shows the signal contributions.

The analysis discussed here is based on the final Babar dataset, corresponding to 471×10^6 $B\overline{B}$ events collected at the peak of the $\Upsilon(4S)$ resonance. The ω meson is identified through its decay to $\pi^+\pi^-\pi^0$ and the ϕ meson through its decay to K^+K^-. Particle identification criteria are applied for the charged pion and kaon candidates, and invariant mass requirements for the ω, ϕ, and $\pi^0 \to \gamma\gamma$ candidates. The B meson candidates are formed by combining two vector-meson candidates that emanate from the same vertex. Standard charmless-B-meson-decay event selection criteria, such as those on the energy-constrained mass $m_{ES} \equiv \sqrt{(E^*_{beam})^2 - (\vec{p}^{\,*}_B)^2}$ and energy difference $\Delta E \equiv |E^*_B - E^*_{beam}|$, are imposed, where E_B and $\vec{p}_B$ are the energy and three-momentum of the B meson candidate and the superscript "*" denotes the center-of-mass frame. For correctly reconstructed signal events, m_{ES} peaks at the B meson mass and ΔE at zero.

The main background arises from continuum events ($e^+e^- \to q\overline{q}$ events, with $q = udsc$). To reduce the continuum contribution, a cut on $|\cos\theta_T|$ is imposed, where θ_T is the angle between the thrust axis of the B meson candidate and the thrust axis constructed from all other particles in the event. (The distribution of $\cos\theta_T$ is peaked near 1 for continuum events and is roughly flat for signal events.) The overall selection efficiency is around 14% for $\omega\omega$ events and 9% for $\omega\phi$ events.

A maximum likelihood fit is performed. The fitted variables are the distributions of a Fisher discriminant, m_{ES}, ΔE, the masses of the two vector-meson candidates, and the helicity angles of the two vector-meson candidates. The Fisher discriminant is constructed using event shape information such as the polar angle of the B meson candidate. For the ω meson, an additional helicity angle relative to our 2006 study [3] is used (thus there are two helicity angles used for the ω meson, and one helicity angle for the ϕ meson): the angle θ of the π^0 in the $\pi^+\pi^-$ rest frame with respect to the direction of the boost from the ω rest frame. Signal events have a $\sin 2\theta$ dependence while the background distribution is flat.

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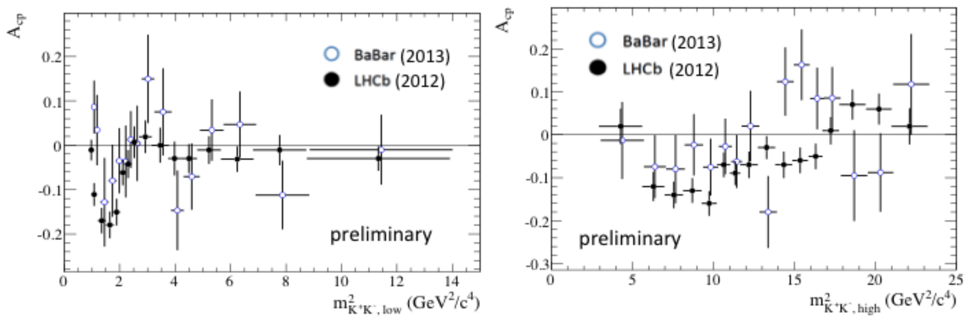

Figure 3: The CP asymmetry A_{CP} observed by the LHCb and Babar experiments as a function of the (left) lower and (right) higher of the two K^+K^- invariant mass values in $B \to K^+K^-K^+$ decays.

The maximum likelihood fit incorporates separate components for signal events, for "peaking" $B\overline{B}$ background channels, i.e., for channels that exhibit peaks in either m_{ES} or ΔE, and for non-peaking background components. The shapes of the signal probability density functions that enter the fit are validated using $B \to D\rho$ control samples. The fitting procedure itself is validated using ensembles of simulated event samples.

Projections of the fit results onto the m_{ES} and ΔE axes are shown in Fig. 2. For $B \to \omega\phi$ decays, no signal is observed, and we set an improved limit on the branching fraction of 0.7×10^{-6} (90% CL). For $B \to \omega\omega$ decays, we observe a signal with 4.4 standard deviation significance including systematic uncertainties. This result constitutes the first evidence for this decay mode. The measured branching fraction, $\mathscr{B}[B \to \omega\omega] = 1.2 \pm 0.3\,(\text{stat.})^{+0.3}_{-0.2}\,(\text{syst.})$, is in agreement with the standard model prediction.

3. CP asymmetry in $B^+ \to K^+K^-K^+$ decays

We next discuss the CP asymmetry in $B^+ \to K^+K^-K^+$ decays, defined by $A_{CP} = [\Gamma(B^-) - \Gamma(B^+)]/[\Gamma(B^-) + \Gamma(B^+)]$. Interference between tree and penguin amplitudes in these decays can lead to CP violation, i.e., to non-zero values of A_{CP}. Deviations from standard model predictions could indicate new physics.

Babar recently published a study of the CP asymmetry in $B^+ \to K^+K^-K^+$ events [3]. This study is an amplitude analysis based on 5269 signal events. No evidence for CP violation in inclusive $K^+K^-K^+$ events was found. For the quasi-two-body mode $B^+ \to \phi K^+$, Babar reported a CP asymmetry $A_{CP} = (12.8 \pm 4.4 \pm 1.3)\%$ that differs from zero by 2.8 standard deviations.

Subsequent to the Babar publication, the LHCb Collaboration presented a study of $B^+ \to K^+K^-K^+$ events based on an event sample of around 22,000 signal events [4, 5]. They observed evidence of CP violation in inclusive $B^+ \to K^+K^-K^+$ decays at the level of 3.7 standard deviations. However, they did not observe a CP asymmetry in the $B^+ \to \phi K^+$ mode. The LHCb analysis is based on the raw asymmetry between B^- and B^+ decays with a correction derived from $B^+ \to J/\psi K^+$ events to account for differing K^+ and K^- detection efficiencies and other detector-induced asymmetries. Thus the approaches of Babar and LHCb are quite different.

The LHCb analysis went further, and examined A_{CP} in bins of $m_{K^+K^-,low}$, which is the lower of the two K^+K^- invariant mass values in the event. They observed a very strong asymmetry

$A_{CP} \approx -20\%$ for $m^2_{K^+K^-,low} \approx 1.6$ GeV^2, as shown by the solid circles in Fig. 3 (left).

To investigate this effect seen by LHCb, Babar performed a new study [6] in which we repeated the LHCb study of A_{CP} versus $m_{K^+K^-,low}$, using the same binning and Dalitz-plot selection requirements in order to better compare the results of the two experiments. The Babar results are shown by the open circles in Fig. 3 (left). It is seen that the Babar data are entirely consistent with the LHCb results. In particular, Babar observes a similar enhancement of A_{CP} at around $m^2_{K^+K^-,low} \approx 1.6$ GeV^2. The Babar data are generally shifted to lower values of $|A_{CP}|$, but $|A_{CP}|$ is higher in the region $m^2_{K^+K^-,low} \approx 1$ GeV^2 of the ϕ meson, which would explain why Babar reported an indication for a CP asymmetry in the ϕK^+ quasi-two-body mode while LHCb did not.

The corresponding results for $m_{K^+K^-,high}$, which is the higher of the two K^+K^- invariant mass values in the $K^+K^-K^+$ events, are shown in Fig. 3 (right). The Babar results are again seen to be consistent with those of LHCb, but shifted systematically higher.

We determine the average difference between the results of the two experiments to be $4.5 \pm 2.1\%$ for Fig. 3 (left) and $5.3 \pm 2.1\%$ for Fig. 3 (right). Note that the LHCb results in these two plots are the raw A_{CP} values, and that the difference between Babar and LHCb is reduced once corrections to the LHCb data are applied. Thus there is a systematic shift of (at most) around two standard deviations between the results of the two experiments, and the results are in general agreement with each other.

4. Summary

We have presented the final Babar update in the search for the charmless vector-vector B meson decay modes $B \to \omega\omega$ and $B \to \omega\phi$. We obtain the first evidence for $B \to \omega\omega$ decays, with a significance of 4.4 standard deviations including systematic uncertainties. The branching fraction is determined to be $\mathscr{B}[B \to \omega\omega] = 1.2 \pm 0.3\,(\text{stat.})^{+0.3}_{-0.2}\,(\text{syst.})$, in agreement with standard model expectations. We improve the limit on the $B \to \omega\phi$ branching fraction to 0.7×10^{-6} (90% confidence level).

In a separate study, we investigate the CP asymmetry in $B \to K^+K^-K^+$ events as a function of the lower of the two K^+K^- invariant mass values. We confirm the LHCb observation of a strong CP asymmetry for $m^2_{K^+K^-,low} \approx 1.6$ GeV^2. The results of the two experiments are shifted relative to one another by around two standard deviations. This difference is still under investigation.

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