Two Recent Results on B Physics from CDF

M.P. Schmidt
for the CDF Collaboration

Department of Physics, Yale University
New Haven, CT 06520

Preliminary results from two recent CDF b physics analyses are presented. The first obtains $\sin(2\beta) = 0.79^{+0.41}_{-0.44}$ from a measurement of the asymmetry in $B^0, \overline{B^0} \rightarrow J/\psi K^0_S$ decays, providing the best direct indication so far that CP invariance is violated in the $b$ sector. The second obtains new results on the parity even ($A_0$ and $A_\parallel$) and odd ($A_\perp$) polarization amplitudes from full angular analyses of $B^0 \rightarrow J/\psi K^{*0}$ and $B^0_s \rightarrow J/\psi \phi$ decays:

$$B^0:\begin{align*}
A_0 &= 0.770 \pm 0.039 \pm 0.012 \\
A_\parallel &= (0.530 \pm 0.106 \pm 0.034)e^{(2.16\pm0.46\pm0.10)i} \\
A_\perp &= (0.355 \pm 0.156 \pm 0.039)e^{(-0.56\pm0.53\pm0.12)i}
\end{align*}$$

$$B^0_s:\begin{align*}
A_0 &= 0.778 \pm 0.090 \pm 0.012 \\
A_\parallel &= (0.407 \pm 0.232 \pm 0.034)e^{(1.12\pm1.29\pm0.11)i} \\
|A_\perp| &= 0.478 \pm 0.202 \pm 0.040
\end{align*}$$

*Presented at the XXXIVth Rencontres de Moriond, Les Arcs 1800, France, 13-20 March 1999.
1 Introduction

A rich program in $b$ production and decay physics has been pursued with data collected by CDF in Run I (1992 – 1995). By making use of a silicon strip vertex detector and the copious production of various species of $b$ hadrons at the Tevatron $\bar{p}p$ collider, we have obtained precise measurements of the $B^0$, $B^+$, and $B_s^0$ lifetimes and the $B^0$ mass. We have observed the decay $B_c \rightarrow J/\psi \ell \nu$, and set the most stringent limits on the decays $B_{d,s} \rightarrow \mu^+ \mu^-$ and $B \rightarrow K(\ast) \mu^+ \mu^-$. We also have obtained competitive measurements on neutral $B$ mixing and ratios of branching fractions for selected $b$ hadron decay modes. Most of these results and others have been published or submitted for publication.

Preliminary results from two more analyses have become available this year. The first analysis builds upon and significantly extends the previously published CDF result on the $CP$ nonconserving parameter $\sin(2\beta)$ as determined from the asymmetry in $B^0, \bar{B}^0 \rightarrow J/\psi K^0_S$ decays. The analysis presented here includes events that are not fully reconstructed in the silicon vertex detector, thereby doubling the available data sample, and uses the combination of three flavor tagging algorithms.

The second analysis obtains results for the polarization amplitudes in the pseudoscalar to vector-vector decays $B^0 \rightarrow J/\psi K^{*0}$ and $B_s^0 \rightarrow J/\psi \phi$. These results are relevant to understanding the decay dynamics of hadrons containing a heavy-quark and provide information relating to the possible use of these decays for studies of $CP$ invariance violation. For example, if the decay $B^0 \rightarrow J/\psi K^{*0}$ were to occur in a parity eigenstate (even or odd) followed by the $CP$ invariant decay $K^{*0} \rightarrow K_S^0 \pi^0$, then this mode could be used as simply as the $B^0 \rightarrow J/\psi K_S^0$ mode for determining $\sin(2\beta)$.

2 Improved Measurement of $\sin(2\beta)$ with $B^0 \rightarrow J/\psi K_S^0$ Decays

It has long been recognized that a measurement of the $CP$ noninvariant asymmetry

$$A_{CP}(t) = \frac{dN(B^0 \rightarrow J/\psi K_S^0)}{dt} - \frac{dN(\bar{B}^0 \rightarrow J/\psi K_S^0)}{dt} + \frac{dN(B^0 \rightarrow J/\psi K_S^0)}{dt}$$

provides a phenomenologically clean method for determining $\sin(2\beta)$. Violation of $CP$ invariance can arise in the Standard Model through a non-trivial phase in the CKM quark mixing matrix. Interference between the direct decay, $B^0 \rightarrow J/\psi K_S^0$, and the decay after mixing ($\bar{B}^0 \rightarrow B^0$) leads to an asymmetry $A_{CP}(t) = \sin(2\beta) \sin(\Delta m t)$. The $B^0 - \bar{B}^0$ mixing frequency is governed by the mass difference, $\Delta m$, between the heavy and light mass eigenstates. The proper time of decay, $t$, is employed in order to achieve maximum sensitivity via a time-dependent measurement of the asymmetry. Previous direct measurements of the asymmetry have been made by OPAL and CDF, the latter result being updated by the analysis presented here.

The CDF measurement of $\sin(2\beta)$ is made possible by the distinctive decay to a final state with all charged particles: $B^0 \rightarrow J/\psi K_S^0 \rightarrow \mu^+ \mu^- \pi^+ \pi^-$. Charged particle three-momenta are determined at CDF with an 84-layer drift chamber (the CTC) that covers the pseudorapidity interval $|\eta| < 1.1$, where $\eta = -\ln[\tan(\theta/2)]$ and $\theta$ is the polar angle in a cylindrical coordinate system in which the $z$ axis coincides with the pp beam line. The $z$ coordinate of the pp interaction is determined with a time projection drift chamber (the VTX) located inside the CTC. The VTX surrounds the silicon vertex detector (the SVX) which consists of four layers of axial silicon strips (providing $r - \phi$ information) located at radii between 2.9 and 7.9 cm and extending $\pm 25$ cm in $z$ from the detector center. The central tracking volume is immersed in a 1.4 T uniform axial magnetic field. The component of charged track momentum transverse to the beam line, $p_T$, is determined with a resolution of $\delta p_T/p_T = [(0.0009 \cdot p_T^2 \text{GeV/c})^2 + (0.0066)^2]^{1/2}$ for tracks well measured in the SVX-CTC.

Electrons and muons are readily distinguished within CDF from other charged particles (pions, etc.) The central tracking volume is surrounded by calorimetry with projective tower geometry which is augmented with a preshower detector and with strip chambers at electromagnetic shower maximum. Electrons are identified by their interactions in the calorimeter and by $dE/dx$ information from the CTC and preshower detectors. Muons in the central region with $p_T > 1.4 \text{ GeV/c}$ typically penetrate
the calorimeter (~5 absorption lengths) and are detected in central muon chambers (85% coverage in azimuth for |η| < 0.6). Additional coverage is provided by central muon upgrade chambers (80% azimuthal coverage, after a total of ~8 absorption lengths) and central extension muon chambers (67% azimuthal coverage for 0.6 < |η| < 1.0, after a total of ~6 absorption lengths).

Candidate events are reconstructed mainly from data collected with a dimuon trigger having a relatively low threshold (p_T(µ) > ∼2 GeV/c). For events with a reconstructed J/ψ → µ^+µ^− decay, Κ_S candidates are formed from pairs of oppositely charged tracks, assumed to be pions, and required to have p_T > 0.7 GeV/c and be well separated from the ¯pp collision envelope. Mass, vertex and pointing constraints are then used in a four particle fit for B_0 candidates.

From 110 pb^{-1} of data collected with CDF the yield of J/ψ Κ_S candidates is 395 ± 31 events with a signal to background of 0.7 for p_T(B) > 4.5 GeV/c. The normalized mass distribution is displayed in Fig. 1 where the data has been divided into two disjoint sub-samples: an SVX sample (202 ± 18 events with a signal to background of 0.9) and a non-SVX sample (193 ± 26 events with a signal to background of 0.5). The SVX sample is the subset of candidates for which both muons had trajectories well measured in the silicon vertex detector. The sample sizes are roughly equal due to the limited acceptance of the SVX (60%); it’s size (±25 cm) is similar to the ~30 cm rms spread in the distribution of ¯pp interactions along the beam axis.

The SVX sample is essentially the same as that employed for the previously published CDF result on sin(2β). The SVX events have the precise decay length information needed to carry out a time-dependent asymmetry measurement. The non-SVX events have less precisely determined decay lengths, but can nevertheless contribute at least via a time-integrated measurement. In fact 30% of the non-SVX events have one muon well measured in the silicon vertex detector.

In order to measure the asymmetry A_{CP} it is necessary to identify (tag) whether the decaying B meson was initially produced as B_0 or B_0. The effectiveness of the tag depends on its efficiency (ε) and its purity. The purity of a tagging algorithm is usually expressed in terms of a dilution factor or fractional difference of right (R) and wrong (W) tags: D = (N_R - N_W)/(N_R + N_W). An impure tagger with dilution D < 1 results in a smaller observable asymmetry: A_{CP}^{obs} = DA_{CP}. The statistical uncertainty for the result on sin(2β) is inversely proportional to √εD^2.

Three tagging algorithms are employed in order to maximize the sensitivity of the measurement. All three methods have been developed and used by CDF for B_0 – B_0 mixing measurements. One of the algorithms employed, a same-side tagging algorithm (SST), exploits charge correlations expected...
Table 1: Percentage efficiencies and dilutions as measured for the flavor tagging algorithms employed. For the SST algorithm, the efficiency values include the fractions of SVX and non-SVX events; thus, the tagging efficiency for the total sample is the sum of the SVX and non-SVX efficiencies.

| type          | tagger          | class | efficiency($\epsilon$) | dilution($D$) |
|---------------|-----------------|-------|-------------------------|---------------|
| same-side     | same-side       | SVX   | 35.5 $\pm$ 3.7          | 16.6 $\pm$ 2.2|
|               | same-side       | non-SVX | 38.1 $\pm$ 3.9          | 17.4 $\pm$ 3.6|
| opposite side | soft lepton     | all events | 5.6 $\pm$ 1.8          | 62.5 $\pm$ 14.6|
|               | jet charge      | all events | 40.2 $\pm$ 3.9          | 23.5 $\pm$ 6.9|

between the $B$ meson flavor and and the charge of pions produced in fragmentation or from the decays of resonances ($B^{*+}$). The SST algorithm employed with the SVX sample in the analysis reported here is identical to that used in the published analysis on sin($2\beta$) and an associated mixing measurement. Appropriate modifications have been made to validate and apply the SST tag to the non-SVX sample. The expected dilution and efficiency for the SST algorithm then largely follows from the previous work.

Two opposite-side tagging algorithms are employed. A soft lepton tagging algorithm (SLT) exploits the correlation of the flavor ($b$ or $\bar{b}$) of the $B$ meson at production with the charge of the lepton from the semileptonic decay of the (opposite-side) $b$ hadron produced in association with it. A jet charge tagging algorithm (JETQ) exploits a similar correlation between the $B$ meson flavor and the momentum weighted sum of charges for a cluster of tracks (a jet) associated with the decay of the opposite-side $b$ hadron. The SLT and JETQ algorithms are very similar to algorithms used in a CDF mixing analysis carried out with a sample of candidate $B$ mesons detected via their semileptonic decays. The $B$ mesons in the mixing analysis sample have a higher $p_T$ (typically a factor of $\sim 2$) than the $J/\psi K_S^0$ events, and this motivates modifications of the SLT and JETQ algorithms. The expected dilutions and efficiencies for the SLT and JETQ tagging algorithms are determined with a sample of 1000 $B^{\pm} \to J/\psi K^{\pm}$ decays and a sample of 40,000 inclusive (non-prompt) $J/\psi \to \mu^+\mu^-$ decays. The SLT and JETQ algorithms are applied to both the SVX and non-SVX event samples.

The tags are defined to be essentially orthogonal; in particular, tracks within a cone of $\sqrt{(\eta^2 + \varphi^2)} < 0.7$ centered on the vector momentum of the $B \to J/\psi K_S^0$ decay can be candidates for an SST tag but are excluded from use for a JETQ tag. Each event can be tagged by zero, one or two algorithms. In the case of two tags, one must be SST. If both SLT and JETQ tags are present the SLT assignment is taken due to its superior (larger) dilution. Tagging information is obtained for 80% of the events in the $J/\psi K_S^0$ sample. Taking into account single and double tags, a combined effective tagging efficiency $\epsilon D^2 = 6.3 \pm 1.7\%$ is obtained.

An unbinned maximum likelihood fit is used to extract a value for sin($2\beta$). The $B^0$ lifetime and $\Delta m_d$ are constrained in the fit to the world average values. The fit includes the SVX and non-SVX samples and treats the decay length uncertainty and dilutions appropriately. The fit allows for prompt and non-prompt background components as well as the possibility of charge asymmetries in the efficiencies and dilutions of the tags. No significant asymmetries are observed in the dilutions or the backgrounds.

The result from the fit is $\sin(2\beta) = 0.79 \pm 0.39\text{(stat)} \pm 0.16\text{(syst)}$. The statistical uncertainty dominates and the systematic uncertainty arises almost entirely from the determination of the dilution parameters with the limited sample of $B^{\pm}$ decays. From this result, a 93% confidence interval of $0.0 < \sin(2\beta) < 1.0$ is obtained for the frequentist approach advocated by Feldman and Cousins. Similar limits are obtained using alternative methods.

The result obtained, $\sin(2\beta) = 0.79^{+0.44}_{-0.44}(\text{stat+syst})$, provides the best direct indication so far that $CP$ invariance is violated in the $b$ quark system. This result is consistent with the Standard (CKM) Model expectation for a large positive asymmetry. Indirect constraints from measurements of other CKM related quantities suggest that $\sin(2\beta)$ is large and positive: $\sin(2\beta) = 0.75 \pm 0.09$. 

Fig. 2 displays the result on $\beta$ on the $\rho - \eta$ plane (following Wolfenstein’s parametrization of the CKM quark mixing matrix.) It is noted that the expected sign of the asymmetry depends on the relative sign of hadronic matrix elements governing mixing in the $K^0 - \bar{K}^0$ and $B^0 - \bar{B}^0$ systems.

Extrapolating to the anticipated luminosity of 2 fb$^{-1}$ in Run II and assuming no improvements in the effective tagging efficiency, an uncertainty on $\sin(2\beta)$ of $\sim 0.08$ is expected.

3 Measurement of Polarization Amplitudes in $B^0 \rightarrow J/\psi K^{*0}$ and $B^0_s \rightarrow J/\psi \phi$ Decays

The decays $B^0 \rightarrow J/\psi K^{*0}$ and $B^0_s \rightarrow J/\psi \phi$ are pseudoscalar to vector-vector decays and in principle have three decay amplitudes which can be determined by studying the angular distributions of the final state particles. These decays can have orbital angular momenta between the $J/\psi$ and $K^*$ (or $\phi$) of 0, 1, or 2, and three matrix elements are needed to describe the transitions to these three eigenstates of the $J/\psi K^*$ (or $\phi$) system. A very useful basis for this description is the transversity basis. In this basis one matrix element, $A_{\perp}$, corresponds to the parity odd, $L = 1$ (P wave), amplitude, and two matrix elements $A_0$ and $A_{||}$ are combinations of the parity even, $L = 0$ and $L = 2$ (S and D wave), amplitudes. Also, $|A_0|^2$ is equal to the longitudinal polarization fraction, $\Gamma_L/\Gamma$, as is commonly defined in the helicity basis.

A determination of the longitudinal polarization is relevant to testing the limitations of theoretical predictions which follow from the factorization hypothesis. The factorization hypothesis assumes that the weak decay amplitude can be described as the product of two independent (hadronic) currents. For these decays the factorization ansatz treats the $J/\psi$ as a current independent of the $B \rightarrow K^*$ ($\phi$) current. One assumes the decay matrix elements factorize naturally into short and long distance (weak and strong) processes which do not interfere with each other. This implies that the matrix elements of the decay be relatively real. The observation of nontrivial phases between the matrix element implies final state interactions (though the absence of nontrivial phases need not rule out the presence of final state interactions).

A measurement of the parity odd amplitude, $A_{\perp}$, is of interest from the point of view of studies of $CP$ invariance. As discussed earlier, the decay mode $B^0 \rightarrow J/\psi K^0_S$ is useful for a determination...
of $\sin(2\beta)$. This is due to the fact that the final state is a $CP$ eigenstate and one weak amplitude contributes to the decay. The decay $B^0\to J/\psi K^0$ can also be of use, when the final state is a $CP$ eigenstate (e.g. $K^{*0}\to K^0_S\pi^0$). A measurement of $\beta$ is most readily extracted if one or the other parity amplitude dominates the decay, otherwise the asymmetry in the decay rates is diluted. The situation holds as well for the decay $B^0\to J/\psi\phi$ which is expected to have a very small $CP$ decay rate asymmetry in the Standard (CKM) Model.

Finally, one of the objectives of studying $B^0_s$ meson decays is to determine the properties of the $B^0_{s,H}$ and $B^0_{s,L}$ states. Since they are very nearly $CP$ eigenstates, they will decay with distinct angular distributions. This can improve the sensitivity of a lifetime difference measurement by adding information beyond the decay time distribution alone.

The events used in this analysis are selected from a sample in which the muons from the $J/\psi$ decay satisfy dimuon triggers employed during Run Ib $(90\,pb^{-1})$. The event selection criteria are similar in spirit to the $J/\psi K^0_S$ analysis discussed above. The main differences are the requirements for $p_T > 2.0$ (1.5) GeV/$c$ for the $K^*$ ($\phi$) and $p_T > 6.0$ (4.5) GeV/$c$ for the $B^0$ ($B^0_s$) candidates. Also two of the four charged tracks in each candidate are required to be well measured in the SVX and a minimum proper decay length of 100 (50) $\mu$m is required for $B^0$ ($B^0_s$) candidates. In principle, this can bias the angular distribution for the $B^0_s$ since the mass eigenstates are approximately $CP$ eigenstates and can have different lifetimes. The mass distributions of the $B$ candidates are shown in Fig. 3.

The decay angular distribution has the following form, expressed in terms of the decay angles of the decay products of the vector mesons:

$$\Omega_{\text{Tn}} \propto 2\cos^2\Theta_{K^*} \left(1 - \sin^2\Theta_T \cos^2\Phi_T\right) |A_0|^2 + \sin^2\Theta_{K^*} \left(1 - \sin^2\Theta_T \sin^2\Phi_T\right) |A_\parallel|^2$$

$$+ \sin^2\Theta_{K^*} \sin^2\Theta_T |A_\perp|^2 + \frac{1}{\sqrt{2}} \sin 2\Theta_{K^*} \sin^2\Theta_T \sin 2\Phi_T \text{Re}(A_0^* A_\parallel)$$

$$+ \sin^2\Theta_{K^*} \sin 2\Theta_T \sin \Phi_T \text{Im}(A_0^* A_\perp) \pm \frac{1}{\sqrt{2}} \sin 2\Theta_{K^*} \sin 2\Theta_T \cos \Phi_T \text{Im}(A_0^* A_\parallel)$$

Note that the last two terms have opposite signs for the decay of a $\bar{B}$ as compared with a $B$. The $B^0$ and $\bar{B}^0$ decays are flavor tagged by the charge of the $K$ meson, but the $B^0_s$ and $\bar{B}_s$ are not distinguishable by their final state particles. Hence, for $B^0_s$ decays information about the phase of $A_\perp$ is lost.
The decay matrix elements are extracted from a likelihood fit with care taken into account for the detector acceptance and residual backgrounds. Fig. 4 shows one sigma contours for the extracted decay matrix elements. For the $B^0$ decay:

\[
A_0 = 0.770 \pm 0.039 \pm 0.012 \\
A_\parallel = (0.530 \pm 0.106 \pm 0.034)e^{(2.16 \pm 0.46 \pm 0.10)i} \\
A_\perp = (0.355 \pm 0.156 \pm 0.039)e^{(-0.56 \pm 0.53 \pm 0.12)i}
\]

and

\[
|A_0|^2 = \Gamma_L / \Gamma = 0.593^{+0.059}_{-0.061} \pm 0.018 \\
|A_\perp|^2 = \Gamma_\perp / \Gamma = 0.126^{+0.121}_{-0.093} \pm 0.028
\]

and for the $B_s^0$:

\[
A_0 = 0.778 \pm 0.090 \pm 0.012 \\
A_\parallel = (0.407 \pm 0.232 \pm 0.034)e^{(1.12 \pm 1.29 \pm 0.11)i} \\
|A_\perp| = 0.478 \pm 0.202 \pm 0.040
\]

and

\[
|A_0|^2 = \Gamma_L / \Gamma = 0.606 \pm 0.139 \pm 0.018 \\
|A_\perp|^2 = \Gamma_\perp / \Gamma = 0.229 \pm 0.188 \pm 0.038
\]

The $B^0$ results are of comparable sensitivity to the results from CLEO; comparable magnitudes are obtained for the three matrix elements, but different central values for the phases. The phases observed in the CDF analysis leave open the possibility of non-trivial final state interactions in the decay. The CDF Run Ib result for the longitudinal polarization is in good agreement with the CDF Run Ia result. This is an important result for tests of factorization, especially when considered along with the observed ratio of branching ratios, $R = B(B \to J/\psi K^*)/B(B \to J/\psi K)$. [18]
The $B_s^0$ results are the first and only ones available for a full angular analysis. Again the Run Ib result for the longitudinal polarization is in agreement with that from Run Ia. Comparison of the $B^0$ and $B_s^0$ results indicates that $SU(3)_{\text{flavor}}$ is a valid approximation. The decays are dominated by the parity even amplitudes but a non-trivial parity odd component is not yet excluded.

4 Conclusions

New results have been presented for a measurement of $\sin(2\beta)$ from $B^0 \to J/\psi K_S^0$ decays and for full polarization analyses of the decays $B^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi \phi$. Besides being of interest in themselves, these results whet the appetite for the richness of the CDF program on $b$ physics during Run II, scheduled to start in the summer of 2000.

Acknowledgements

This work would not be possible without the vital contributions of the staff at Fermilab and all the members and technical staff of the collaborating institutions, and support from the funding agencies. The author would like to thank H. Lipkin for bringing the transversity basis to our attention and acknowledge illuminating correspondence and discussions with I. Dunietz and J. Rosner.

References

1. [http://www-cdf.fnal.gov/physics/new/bottom/bottom.html](http://www-cdf.fnal.gov/physics/new/bottom/bottom.html)
2. F. Abe et al., the CDF Collaboration, *Phys. Lett.* **81**, 5513 (1998).
3. A.B. Carter and A.I. Sanda, *Phys. Rev. Lett.* **45**, 952 (1980), *Phys. Rev. D* **23**, 1567 (1981); I.I. Bigi and A.I. Sanda, *Nucl. Phys.* B **193**, 85 (1981).
4. K. Ackerstaff et al., the OPAL Collaboration, *Eur. Phys. J.* C **5**, 379 (1998).
5. M. Gronau, A. Nippe, and J.L. Rosner, *Phys. Rev. D* **47**, 1988 (1993); M. Gronau and J.L. Rosner, ibid., **49**, 254 (1994).
6. F. Abe et al., the CDF Collaboration, *Phys. Lett.* **80**, 2057 (1998), *Phys. Rev. D* **59**, 032001 (1999).
7. F. Abe et al., the CDF Collaboration, FERMILAB-PUB-99/019-E, submitted to Phys. Rev. D.
8. [http://www-cdf.fnal.gov/physics/new/bottom/cdf4855/cdf4855.html](http://www-cdf.fnal.gov/physics/new/bottom/cdf4855/cdf4855.html)
9. G.J. Feldman and R.D. Cousins, *Phys. Rev. D* **57**, 3873 (1998).
10. S. Mele, *Phys. Rev. D* **59**, 113011 (1999). See also P. Paganini, F. Parodi, P. Roudeau and A. Stocchi, *Phys. Scripta* **58**, 556 (1998) and F. Parodi, P. Roudeau and A. Stocchi, [hep-ph/9802283](http://arxiv.org/abs/hep-ph/9802283) and [hep-ph/9903063](http://arxiv.org/abs/hep-ph/9903063).
11. L. Wolfenstein, *Phys. Rev. Lett.* **51**, 1945 (1983).
12. Y. Grossman, B. Kayser and Y. Nir, *Phys. Lett.* B **415**, 90 (1997); see also I.I. Bigi and A.I. Sanda, [hep-ph/9811488](http://arxiv.org/abs/hep-ph/9811488).
13. [http://www-cdf.fnal.gov/physics/new/bottom/cdf4672/cdf4672.html](http://www-cdf.fnal.gov/physics/new/bottom/cdf4672/cdf4672.html)
14. A.S. Dighe, I. Dunietz, H.J. Lipkin and J.L. Rosner, *Phys. Lett.* B **369**, 144 (1996).
15. G. Valencia, *Phys. Rev. D* **39**, 3339 (1989); G. Kramer and W.F. Palmer, *Phys. Rev. D* **45**, 193 (1992).
16. A.S. Dighe, I. Dunietz and R. Fleischer, *Eur. Phys. J.* C **6**, 647 (1999); A. Dighe and S. Sen, *Phys. Rev. D* **59**, 074002 (1999).
17. [http://www-cdf.fnal.gov/physics/new/bottom/cdf4672/cdf4672.html](http://www-cdf.fnal.gov/physics/new/bottom/cdf4672/cdf4672.html)
18. C.P. Jessop, et al., the CLEO Collaboration, *Phys. Rev. Lett.* **79**, 4533 (1997).
19. F. Abe et al., the CDF Collaboration, *Phys. Rev. Lett.* **75**, 3068 (1995).
20. For example see: M. Gourdin, A.N. Kamal and X.Y. Pham, *Phys. Rev. Lett.* **73**, 3355 (1994); H.Y. Cheng, *Phys. Lett.* B **395**, 345 (1997).
21. F. Abe et al., the CDF Collaboration, *Phys. Rev. D* **58**, 072001 (1998).