Studies of B^0 Decays for Measuring $\sin(2\beta)$

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Future asymmetric $e^+e^- \to \Upsilon(4S)$ B factories are being constructed to search for CP violation in B^0 decays. It is hoped that a CP asymmetry may be observed in B^0–$\overline{B}^0$ mixing in analogy with that found in neutral kaons. In this mixing measurement, B^0 decays to CP eigenstates, such as the rare decay $B^0 \to \psi K_S$, may provide information on the CKM angle $\sin(2\beta)$. I discuss decay additional CP eigenstate branching ratios measured by the CLEO experiment that may be used by future B factories to measure $\sin(2\beta)$.

I. INTRODUCTION

An important part of the B factory program at SLAC and KEK will be to search for CP violation in the mixing and decay of neutral B mesons. In close analogy with the kaon system, the weak interaction allows mixing of the B^0 and the $\overline{B}^0$ through a second-order $\Delta B = 2$ transition. The CP violation in this picture results from the interference between the amplitude for the decay $B^0 \to f$ to some CP eigenstate f and the amplitude for mixing to occur first and then the decay, $B^0 \Rightarrow \overline{B}^0 \to f$. When the two amplitudes have a relative weak phase, CP violation results. Such weak phases arise in the Standard Model because of the complex CKM matrix [1].

In the Wolfenstein parameterization of the CKM matrix [2], the phase of V_{ub} is $\tan^{-1}(\eta/\rho)$ and both the CKM elements V_{ub} and V_{td} are expected to have large phases. Thus it is hoped CP violation may be observed in the B system. Figure 1 shows schematically the current experimental bounds [3] on the CKM phase (ρ, η) from B_d^0 mixing, from measurements of V_{ub}/V_{cb} and from limits on B_s mixing. Also shown is the bound from measurements of ε_{K} in neutral kaons. Overlaid on the figure is a triangle whose sides are related to products of CKM elements that results from the requirement that the CKM matrix is unitary [4]: $V_{ub}V_{ud}^* + V_{cb}V_{cd}^* + V_{tb}V_{td}^* \approx V_{ub} + \lambda V_{cb} + V_{td}^* = 0$ The angles α, β, and γ are all, in principal, measurable from decays of B mesons.

The phenomonon of B^0 mixing is described in a similar way to the mixing of the neutral kaons: Initially pure $|B^0\rangle$ and $|\overline{B}^0\rangle$ states are written as orthogonal mixtures of heavy and light B states. Because the heavy and light states each evolve with their own time- dependences, there is a quantum-mechanical oscillation of an initially pure B^0 or $\overline{B}^0$. The weak (CKM) phases in the mixing as well as in the decay amplitudes cause a CP asymmetry in the mixing and decay of initially pure neutral B's as they time-evolve:

$$A_f(t) = \frac{, (B_{phys}^0(t) \to f) - , (\overline{B}_{phys}^0(t) \to f)}{, (B_{phys}^0(t) \to f) + , (\overline{B}_{phys}^0(t) \to f)} \tag{1}$$

In the B system it is possible to cleanly extract the weak phases from such asymmetries, in contrast with the situation in kaon mixing. In the Standard Model the asymmetry for B_d^0 mixing reduces to [6,7]

$$A_f(t) = -\mathrm{Im}\alpha_f \sin(\Delta m_B t) \tag{2}$$

where

$$\alpha_f = \eta_{CP} \left(\frac{q}{p}\right)_B \frac{\langle f|H_{weak}|\overline{B}_q^0\rangle}{\langle f|H_{weak}|B_q^0\rangle} \left(\frac{q}{p}\right)_K \tag{3}$$

and $\eta_{CP} = \pm 1$ is the CP sign of the final state f. The factor $(q/p)_B$ describes the weak phases in the B mixing, and the factor $(q/p)_K$ appears whenever the final state f has a K_{S} or K_{L} to account for kaon mixing in addition to B mixing phases. The parameter Δm_B is the $B_q^0 - \overline{B}_q^0$ mass difference (for either neutral B_s^0 or B_d^0 mesons).

For B_d^0 mesons, the phase $(q/p)_{B_d} = \arg(V_{td}/V_{td}^*)$ from the presence of intermediate top quarks in the box diagram describing $B_d - \overline{B}_d$ mixing. [6,7] The phase of the decay amplitudes depends upon the quark to which the b decays. For $b \to c$ decays, there is no weak phase since V_{cb} is almost real. [8] Thus $b \to c$ decays in B_d^0 mixing gives us

$$\alpha_f = \eta_{CP} \arg\left(\frac{V_{td}}{V_{td}^*}\right),$$
$$A_f(t) = -\eta_{CP} \sin(2\beta) \sin(\Delta m_B t)$$

It should be noted that in extracting the value of $\sin(2\beta)$ from the mixing asymmetry, there is a four-fold ambiguity in the actual value of β that is inferred from this measurement. In principle, present data, as shown in Figure 1, along with recent indications from the CDF experiment [9], indicate that $\text{sign}[\sin(2\beta)] > 0$. It may be further possible [10] to furthermore remove the last two-fold ambiguity, as mentioned in Section VIII.

In this paper I review several branching ratio measurements of $b \to c$ transitions of B_d^0 mesons that are relevant to future B factories in measuring $\sin(2\beta)$. The modes discussed are:

$$B^0 \to \psi K_\text{S} \quad B^0 \to \psi K_\text{L} \quad B^0 \to \psi(2\text{S})K_\text{S}$$
$$B^0 \to \psi\eta \quad B^0 \to \chi_{\text{c}1}K_\text{S} \quad B^0 \to \psi\pi^0$$
$$B^0 \to \psi K^{*0} \quad B^0 \to \psi(2\text{S})K^{*0} \quad B^0 \to D^{*+}D^{*-}$$

The above branching ratios were measured by the CLEO experiment running at the symmetric $e^+e^- \to \Upsilon(4\text{S}) \to B\overline{B}$ CESR collider at Cornell Unversity. [11] The goal in studying these decays is to see how many events may be used for studying CP violation above and beyond the so-called "gold-plated" mode of ψK_S. The last three decay modes are of course not CP eigenstates, but may still be used for studying CP violation, as is discussed below.

The observation of CP violation in B^0 mixing and decay is a powerful first step toward proving CP violation is not simply a feature inherent to neutral kaons. The observation of this kind of CP violation will be an important confirmation of the CKM model [12].

II. DATA SAMPLE

Most of the studies presented in this paper represent the yield of 6.3 fb^{-1} of data, which amounts to ≈ 6 million $B\overline{B}$ pairs. An additional 3 fb^{-1} was taken 60 MeV below the $\Upsilon(4\text{S})$ to study backgrounds from continuum $e^+e^- \to q\overline{q}$ light quark production.

At the $\Upsilon(4\text{S})$, it is convenient to use two kinematic constraints in reconstructing B mesons from their daughter particles. Noting that the B energy is exactly the $e^\pm$ beam energy, we form the invariant mass of B candidates from $m_B^2 = \sqrt{E_{beam}^2 - (\Sigma\mathbf{p}_i^2)}$ since the beam energy is very well measured. Furthermore, we calculate the total energy E_B of our B candidates and form the variable $\Delta E = E_B - E_{beam}$ which should peak at zero for true signal. Resolutions on these quantities are $\sigma(m_B) \sim 2$–3 MeV and $\sigma(\Delta E) \sim 10$–20 MeV.

While the analyses which identify final-state ψ mesons differ slightly in their selection criteria, all of these studies were done by first selecting events where the ψ decays to ee or $\mu\mu$ pairs, which comprise just 12% of the ψ branching ratio. For these analyses, lepton selection criteria were imposed for both the daughter leptons in the ψ decays, so the efficiencies for reconstructing the ψ are typically $\sim 40\%$. In future B factory experiments it may be possible to relax such selection criteria and thereby increase the reconstruction efficiencies for these decays. [13]

To suppress the ψ's which come from continuum $e^+e^- \to c\overline{c}$, a cut of $P_\psi < 2.0\text{GeV}/c$ was imposed. Thus, unless explictely mentioned otherwise, the backgrounds to the modes considered here from $B \to \psi X$ decays. CLEO has previously measured the inclusive $B \to \psi$ momentum distribution [14], and our Monte Carlo model of B decays, which includes several different exclusive ψ modes, reproduces very well the observed ψ momentum distribution. Therefore, many of the background estimates, which rely heavily on our Monte Carlo, are well modelled.

III. $B^0 \to \psi K_\text{S}$

The decay $B^0 \to \psi K_\text{S}$ with $K_\text{S} \to \pi^+\pi^-$ is a so-called "gold-plated" CP eigenstate because the distinctive signature of two leptons from the ψ and two charged tracks emanating from a point detached from the collision point. With efficiencies of $\sim 40\%$ for the ψ and $\sim 75\%$ for reconstructing the $K_\text{S} \to \pi^+\pi^-$, we observe 75 events in 6.3 fb^{-1}, as shown in Figure 2(a). In Figure 2(a), we plot the ΔE of our ψK_S candidates $vs.$ their mass. All quantities are plot in units of the experimental resolution (see Section 2), so signal is expected to lie in a region ± 3 units from the expected values. Using our $B^0 \to \psi X$ MC, we expect ≤ 0.1 events background in the sample. The branching ratio measured is $\mathcal{B}(B^0 \to \psi K_\text{S}) = (4.6 \pm 0.06 \text{ stat.} \pm 0.06 \text{ sys.}) \times 10^{-4}$, where the first uncertainty is due to statistics and the second

due to systematic uncertainties (in reconstruction efficiencies and the total number of $B\overline{B}$ in the sample from which these candidates were selected). It is hoped we can add to this 75 events using the other decay modes below.

IV. $B^0 \to \psi K_{\mathbf{S}}$, $K_{\mathbf{S}} \to \pi^0 \pi^0$

To identify $K_{\mathbf{S}} \to \pi^0\pi^0$ decays, we search for pairs of photons in the CsI calorimeter which are consistent with the π^0 mass using very mass cuts. When two such pairs are found, then the vector defined by the primary collision point and the center- of-energy of the four photons in the calorimeter is used to define the $K_{\mathbf{S}}$ flight direction. The hypothesized $K_{\mathbf{S}}$ flight distance before decaying is then varied until the two π^0 pairings give the best π^0 masses. The $K_{\mathbf{S}}$ is not used in the constraint, but it is found that the $K_{\mathbf{S}}$ mass resolution improves from ~ 20 MeV to ~ 6 MeV with this procedure. The $K_{\mathbf{S}} \to \pi^0\pi^0$ reconstruction efficiency is 25%, which, combined with the ψ reconstruction efficiency, yields an overall efficiency of about 10%. At an asymmetric B factory one benefits from an additional constraint of matching the K^0 origin to the B^0 decay point as measured by the ψ decay.

We observe a signal of 15 events, with an expected background of just 0.7 events from what is believed to be random photons incorrectly paired with a ψ from B decays. However, we are investigating the possible contamination to the sample from $B^0 \to \psi K^*$ decays, since these can readily lend some photons and since the ψK^{*0} decay mode has a strong CP component. This yield, when combined with the reconstruction efficiency above, yields a branching ratio of $\mathcal{B}(B^0 \to \psi K_{\mathbf{S}}) = (6.1 \pm 1.6 \text{ stat.} \pm 0.13 \text{ sys.}) \times 10^{-4}$ (see Table 1), consistent with our result in Section III. More importantly, this decay mode adds 15 more events to our sample of 75 for studying CP violation.

V. $B^0 \to \psi K_{\mathbf{L}}$

The $\psi K_{\mathbf{L}}$ mode is interesting because in principle it presents the same (large) number of events for studying CP asymmetries as does $\psi K_{\mathbf{S}}$, but the $\psi K_{\mathbf{L}}$ has the opposite CP. It should therefore exhibit an asymmetry equal in magnitude but opposite in sign as the gold-plated mode. The difficulty is that the $K_{\mathbf{L}}$ flight path is ~ 1–2 m, so it doesn't decay within the CLEO tracking volume. It is still plausible to detect the $K_{\mathbf{L}}$'s, however, because the CLEO CsI calorimeter is 0.81 λ_{int} in length, hence approximately 65% of the $K_{\mathbf{L}}$ interact in the calorimeter and initiate a shower that exceeds 100 MeV in energy. Thus, the signature for the $B^0 \to \psi K_{\mathbf{L}}$ decay is the lepton pair from the ψ plus a small calorimeter shower from the $K_{\mathbf{L}}$.

The $K_{\mathbf{L}}$ shower is a nuclear interaction, is quite broad in comparison to showers from γ's. In fact, often additional nearby showers are created as nuclear fragments travel some distance. Such shape distinctions are used in the selection to successfully reject over 90% of γ showers. In fact, of the 66 $\psi K_{\mathbf{L}}$ candidates found, only 10 have showers that are due to random photons incorrectly paired with a ψ; all the rest are real $K_{\mathbf{L}}$.

The $K_{\mathbf{L}}$ defines its direction, but not its energy. We use E_ψ and $\mathbf{p}_\psi$ along with the $K_{\mathbf{L}}$ direction to reconstruct m_B, but loose the ΔE constraint. To suppress backgrounds from $B^- \to \psi K^{(*)-}$ we reject events which have an additional track that makes a mass ≥ 5 GeV. Furthermore, we veto events where the $K_{\mathbf{L}}$ candidate shower makes the π^0 mass when paired with any other photon in the event in order to reject backgrounds from $B^0 \to \psi K_{\mathbf{S}}$.

Figure 2(b) shows the results of this search: 66 events are found in 6.7 fb^{-1} of data, where 35 are expected to be from signal, 31 from backgrounds. As stated earlier, most of these backgrounds are from real $K_{\mathbf{L}}$'s from $\chi_{\mathrm{c}1} K_{\mathbf{L}}$, ψK^{*0}, and ψK^{*+}. The CP dilution of these backgrounds is 15 events.

We have not studied reconstruction efficiencies for this decay mode, although they can be inferred from the yield of 35 events in 6.6 fb^{-1} and the known branching ratio for $\psi K_{\mathbf{S}}$.

VI. $B^0 \to \psi \pi^0$ / $\psi \eta$

The $\psi \pi^0$ mode has the same CP and tests a similar Feynman diagram to the often-cited decay mode $B^0 \to D^+ D^-$. [10] It is color-suppressed relative to $D^+ D^-$, but perhaps $\psi \pi^0$ will yield more net events because the $D^+ D^-$ channel

has few subsequent decay modes which can be reconstructed. The $\psi\pi^0$ mode would presumably exhibit a asymmetry of $+\sin(2\beta)$. Because it is the Cabibbo-suppressed version of the ψK^0, we can predict the branching ratio will be $\mathcal{B}(B^0 \to \psi\pi^0) = (f_\pi/f_K)^2 \tan^2\theta_C \, \mathcal{B}(B^0 \to \psi K^0) \sim 6 \times 10^{-5}$ or, by isospin conservation, $\mathcal{B}(\psi\pi^0) = 0.5 \times \mathcal{B}$ $(\psi\pi^-) \sim (2.5 \pm 1.5) \times 10^{-5}$, where I've used the previously published CLEO result [15] for $\psi\pi^-$.

We reconstruct $\pi^0 \to \gamma\gamma$ decays in the CsI calorimeter, which has an efficiency of $\sim 60\%$. We observe 7 candidate events with the background expected to be 0.7 events. The background comes predominantly from real ψ's from B decay paired with random γ's in the event which accidentally form the π^0 mass. With a net detection efficiency of 24.3%, we obtain a branching ratio of $\mathcal{B}(B^0 \to \psi\pi^0) = (0.34 \pm 0.16 \text{ stat.} \pm 0.04 \text{ sys.}) \times 10^{-4}$. We used the procedure of Feldman and Cousins [16] to obtain the 68% C.L. intervals for the Poisson signal mean.

The $\psi\eta$ decay has the same CP as $\psi\pi^0$, so should exhibit the same asymmetry. By isospin, we might expect that $\mathcal{B}(\psi\eta) = \frac{1}{3} \times \mathcal{B}(\psi\pi^0)$. We searched for this mode using $\eta \to \gamma\gamma$ decays ($BR = 39\%$). In 6.3 fb^{-1} no events were seen.

VII. $B^0 \to \chi_{\text{C1}} K_{\text{S}}$

This final state has the same CP as the ψK_{S}, so should have the same sign asymmetry. We select this decay mode by searching for $\chi_{c1} \to \psi\gamma$, $\psi \to ll$, and $K_{\text{S}} \to \pi^+\pi^-$ decays. In 6.3 fb^{-1} 6 events were seen on a background of 0.6 events. The net detector efficiency is 16%, giving a branching ratio of $\mathcal{B}(B^0 \to \chi_{c1} K^0) = (4.5^{+2.8}_{-1.8} \pm 0.9) \times 10^{-4}$. Again, the prescription of Feldman and Cousins [16] was used. The background is expected to consist of random combinations of ψ's and γ's. We are investigating the explicit contribution from ψK^*.

VIII. $B^0 \to \psi(2\text{S}) K^{(*)0}$

The $\psi(2\text{S}) K_{\text{S}}$ mode is a CP eigenstate and the branching ratio is reported here for the first time. The $\psi(2\text{S}) K^{*0}$ mode has previously been observed by CDF [17] and is not a CP eigenstate: because the two vector particles originate from a spin-0 B^0, there is an additional factor of $(-1)^l = \pm 1$ in the final state CP due to orbital angular momentum between the particles. Even though the $\psi(2\text{S}) K^{*0}$ mode is a superposition of two CP eigenstates, it is hoped that a single CP state may dominate as with the decay $B^0 \to \psi K^{*0}$ earlier observed by CLEO and CDF. [18] Even if both CP states are prominent, however, Dunietz has suggested that an angular analysis may be used to separate the two CP components. [19] In this case, one must look at an angular distribution asymmetry that develops with proper decay time of the B^0 instead of just a decay rate asymmetry, so this analysis would require substantially more data.

The $\psi(2\text{S})$ is reconstructed through its l^+l^- ($BR = 12\%$) and $\psi\pi^+\pi^-$ ($BR = 32\%$) decays, and both $K^{*0} \to K^+\pi^-$ ($BR = 67\%$) and $K^{*0} \to K_{\text{S}}\pi^0$ ($BR = 17\%$) decays are considered. In this particular analysis the lepton identification was somewhat more stringent than the previous analyses, hence the efficiencies are somewhat lower (see Table 1). In the case of the $\psi(2\text{S}) K^{*0}$ mode, the systematic uncertainties are somewhat larger due to our knowledge of the unknown helicity amplitudes in this channel (we assume , $_{\text{L}}/$, $= 0.5$, and theoretically 0.5 - 0.7 is expected. Note that CDF and CLEO measure , $_{\text{L}}/$, $= 0.52 \pm 0.08$ for ψK^{*0} decays [18]).

A total of 15 $\psi(2\text{S}) K_{\text{S}}$ and 21 $\psi(2\text{S}) K^{*0}$ candidates are observed (see Table 1). The backgrounds, totalling 0.4 ± 0.2 and 1.9 ± 0.6 events, respectively, are predominantly due to random combinatorics, but also from $B^- \to \psi(2\text{S}) K^{(*)-}$ decays. The relative yields of different $\psi(2\text{S})$ and K^* decay modes is consistent with the different detection efficiencies and branching ratios.

In addition to being a possible avenue for extracting $\sin(2\beta)$, the $\psi(2\text{S}) K^{*0}$ mode presented here and the ψK^{*0} earlier measured by CLEO [18] may help resolve two of the four-fold ambiguities in the extracted value of β. The time-development of $B^0 \to \psi^{(')} K^{*0}$ decays contains additional terms due to the interference between the CP=+1 and CP=-1 components. This additional interference results in additional terms proportional to $cos(\beta)\sin(\Delta m_B t)$, hence a detailed measurement of this decay amplitude may eventually resolve the sign of $\cos(\beta)$ and remove two of the ambiguities for β. Unfortunately, the $K^{*0} \to K_{\text{S}}\pi^0$ decay mode has a quarter of the decay rate and less than half

of the efficiency of the $K^+\pi^-$ mode, so gives a factor 9 fewer events in our sample; thus, such a resolution will not come concurrently with a measurement of $\sin(2\beta)$.

IX. $B^0 \to D^{*+}D^{*-}$

Like the yet unobserved decay mode $B^0 \to D^+D^-$, this decay mode is not expected to be color-suppressed (as is $\psi\pi^0$), but it is expected to be Cabibbo-suppressed relative to the more prevalent and previously observed decay $B^0 \to D_S^{*+}D^{*-}$. [20] So, we might expect a branching ratio for $D^{*+}D^{*-}$ of approximately 0.1%. Like the case of the $\psi^{(')}K^{*0}$, this mode is mixture of (+) and (-) CP eigenstates, so a mixing analysis works if one of the amplitudes dominates or one does a time-dependent measurement of an angular asymmetry [19].

A more complete description of this analysis has recently been published. [21] Here a brief description is given. To reconstruct this mode, both $D^{*+} \to D^0\pi^+$ ($BR = 67\%$) and $D^{*+} \to D^+\pi^0$ ($BR = 33\%$) are used, although for background reasons only $B^0 \to (D^0\pi^+)(\overline{D}^0\pi^-)$ and $B^0 \to (D^+\pi^-)(\overline{D}^0\pi^-)$ modes were considered. A total of five D^0 and six D^+ decay modes were considered.

To suppress background, two techniques were employed. The first was kinematic, in which a χ^2 variable was constructed to compare the reconstructed D and D^* masses for candidates within a given event with the known values. [5] The combinations of particles within an event with the best χ^2 was chosen, and this combination had to have a $\chi^2 < 20$ (xx% efficient for signal while xx% efficient for random $B\overline{B}$ and $c\overline{c}$ backgrounds). The second technique was topological, requiring the flight distance between the D and $\overline{D}$ decay vertices, as measured by the silicon vertex detector, to be inconsistent with zero given our experimental resolutions. [22] This cut was used for events where there was a slow π^0 from the D^* decay.

The results of the search are shown in Figure 3: 4 candidates were found. The background, expected to be 0.4 events, is due to $e^+e^- \to c\overline{c}$ continuum and to $B \to D + X$ decays, where a D and a random π are incorrectly paired to make a D^*. The probability of 0.4 events expected background fluctuating to 4 observed events is 1.1×10^{-4}.

The branching ratio is determined to be $(9.0^{+6.0}_{-4.3} \pm 1.4) \times 10^{-4}$, consistent with our expectations and actually quite comparable to the ψK_S mode. Unfortunately, the reconstruction efficiency is quite small here, just $\sim 9 \times 10^{-4}$, which is in part due to the 8% from all the branching ratios of the D's and D^*'s, but also to the 1% efficiency for reconstructing these high multiplicity decays. We are currently investigating the possibility of only partially reconstructing one of the D^*'s in this decay, and it is furthermore possible that the reconstruction efficiency will be higher at an asymmetric B factory due to the Lorentz boost of the B.

X. SUMMARY

Table 1 shows the yields for the CP eigenstates summarized in this paper. In 6.6 fb^{-1}, 140 events are found amongst all the modes after dilutions are accounted for. Thus, in a 30 fb^{-1} dataset which might be accumulated by one of the B factories in one year's run, one could anticipate 640 events for studying $\sin(2\beta)$. Furthermore, as discussed in Section 2, some of the selection criteria in these various searches have not been optimized for CP studies, hence the efficiencies might be increased by another factor of ~ 1.6, giving an anticipated number of events (after dilution) to just over 1000 when all modes are included. Furthermore, one can hope for additional background rejection when working at an asymmetric collider. Even ignoring such gains, however, one should be able to measure $\sin(2\beta)$ with an error of ± 0.1.

The fact that the 3-generation Standard Model with a single Higgs multiplet has just one independent CP-violating phase makes all the CP-violating effects all very strongly constrained. It will be of great interest to see whether the pattern of CP violation in B decays agrees with the prediction of the CKM model, or whether new physics will have to be invoked to understand the (hopefully many!) manifestations of CP violation observed in the next few years.

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[8] For $b \to u$ decays, there is a phase from V_{ub}/V_{ub}^*, as discussed in [12].

[9] See the talk of Dr. Jonathan Lewis at this conference.

[10] Babar Physics Book, see Chapter 5, "Determination of β," Y. Karyotakis, L. Olivier, J. Smith, and W. Toki, eds.

[11] For a description of the CLEO detector, please see the summary of the talk given by Dr. John Urheim at this conference.

[12] Note that the observation of CP violation in B^0 mixing still does not refute the so-called "superweak" theory. To truly confirm the KM model, so-called "direct CP violation" must be observed, such as by looking for decay rate asymmetries like $B^\pm \to \pi^\pm \pi^0$, $B^\pm \to K^\pm \pi^0$, *etc*, which was discussed at this conference in the talk of Dr. Frank Wuerthwein.

[13] For an analysis of $\psi K^{(*)}$ decays in which the lepton identification criteria for one of the ψ tracks is relaxed, see the talk by S. Schuh, "Measurement of the Ratio $f_\pm/f_{00}$," given at the American Physical Society Centenary Meeting, Atlanta, March 1999.

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TABLE I. CP sign, number of events, background, CP dilution (in events), reconstruction efficiency (including daughter decay branching ratios), and branching ratio for the CP eigenstates reported in this paper. All results are for 6.3 fb^{-1} of data.

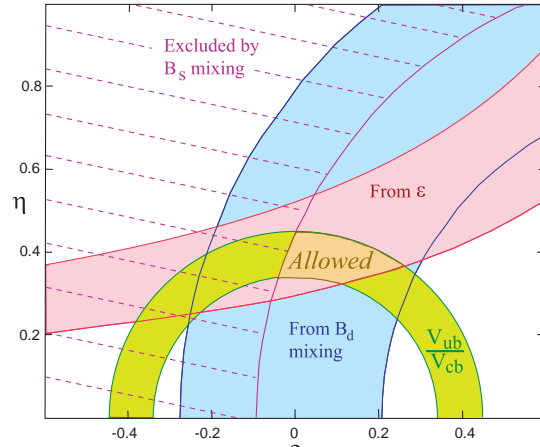| Decay Mode	CP	# Events	Back- ground	CP Dilution (evts.)	Reconstruction $\epsilon(\%)$	$\mathcal{B}$ $(\times 10^{-4})$
$B^0 \to \psi K_S$	-1	75	0.1	0.05	30	4.6 ± 0.8
$B^0 \to \psi K_S$, $K_S \to \pi^0 \pi^0$	-1	15	0.7	0.35	9.6	6.1 ± 2.1
$B^0 \to \psi K_L$	$+1$	66	31	10		
$B^0 \to \psi(2S) K_S$ [a]	-1	15	0.4	0.2	0.94	5.2 ± 1.6
$B^0 \to \chi_{c1} K_S$	-1	6	0.6	0.3	16.3	$4.5^{+2.8}_{-1.8}$
$B^0 \to \psi \pi^0$	$+1$	7	0.6	0.3	24.3	0.34 ± 0.16
$B^0 \to \psi \eta$	$+1$	0	0.1	0.05	15.3	< 0.49 (90% C.L.)

[a]This analysis based on 5.6 fb^{-1}

FIG. 1. Experimental bounds on the parameters ρ and η of the CKM matrix. The allowed region is given by the intersection of the bands. Overlaid is a triangle which results from the requirement that the CKM matrix is unitary [3].
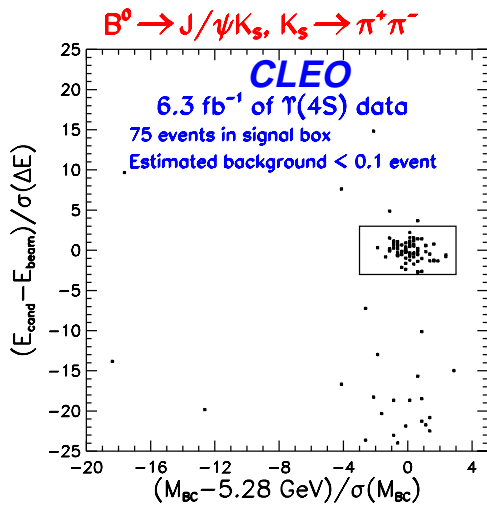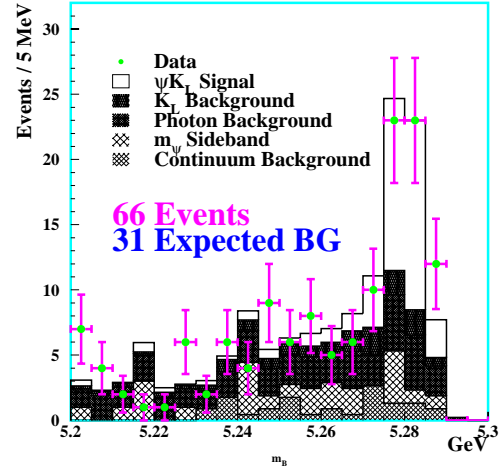

FIG. 2. (a) Reconstructed mass m_B of $B^0 \to \psi K_S$ candidates vs. their ΔE. (b) Reconstructed mass for $B^0 \to \psi K_L$ candidates, indicating CLEO data (points) and expectations for signal (open histogram) and various backgrounds (shaded histograms).
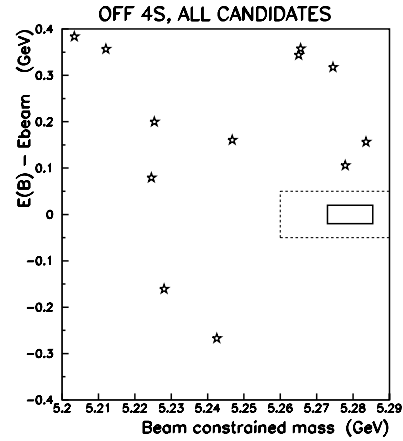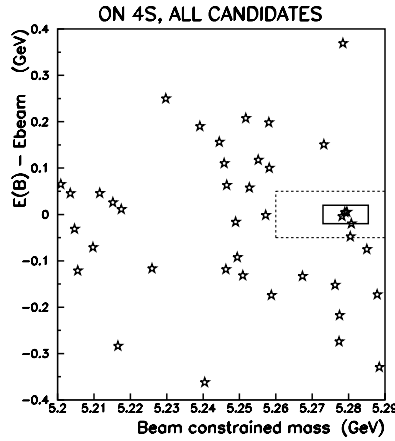

FIG. 3. Reconstructed mass m_B of $B^0 \to D^{*+} D^{*-}$ candidates vs. their ΔE (a) for data taken at the $\Upsilon(4S)$ resonance; (b) for $e^+ e^- \to q\bar{q}$ light quark backgrounds (including $c\bar{c}$), as studied 60 MeV below the $\Upsilon(4S)$.