Recent Results on Hadronic B Decays from CLEO

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Outline

Introduction to CLEO and CESR

$B \to \psi K^{(*)}$

- Branching Ratios.
- Full Fit to ψK^* Decay Amplitudes.

Search for $B \to D^{(*)+} D^{(*)-}$.

$B \to D^{(*)} X$

- Branching Ratios.
- Charm Counting.

Related Projects and Conclusions.

CLEO and CESR

Cornell Electron Storage Ring: e^+e^- at $\sqrt{s} \simeq 10$ GeV.

- World's best collider luminosity!

Continuum (below resonance):

- $e^+e^- \to \gamma^* \to e^+e^-, \mu^+\mu^-, \tau^+\tau^-, u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}$
- Also, $\gamma\gamma \to X$

On4s (on resonance):

- $e^+e^- \to \Upsilon(4s) \to B\bar{B}$, and continuum
- $|P_B| \simeq 350$ MeV/c

CLEOII Dataset: $3.2 fb^{-1}$ On4s + $1.6 fb^{-1}$ continuum.

CLEO2.5: Si Vertex Detector, change chamber gas to He-Propane.
$> 2 fb^{-1}$ so far...expect total of $\sim 5 fb^{-1}$

CLEOII: 4π collider detector

- 1.5T magnetic field, 3 concentric drift chambers
- dE/dx + Time-of-Flight for particle ID
- Excellent CsI E-M Calorimeter
- Muon System

The CLEOII Detector

Full Reconstruction of B Mesons

Symmetric beam energies $\longrightarrow E_B = E_{beam}$.
E_{beam} is well-known.

Key variables for a B candidate are:
(sums are over daughter particles)

$$\Delta E \equiv \sum E_i - E_{beam}$$

This peaks at zero for real events.
Sensitive to particle mis-ID and missing particles.

$$M_B \equiv \sqrt{E_{beam}^2 - |\sum \vec{P}_i|^2}$$

Using E_{beam} in place of $\sum E_i$ improves mass resolution by about a factor of 10 in two-body decays.

$B \to \psi K^{(*)}$ Physics

$B \to \psi K_S$ is of interest to measure CP-violation, in particular the CKM unitarity triangle angle β.

$B \to \psi K^*$ can *also* be used, *if* we can deal with the mixture of CP-odd and CP-even decays.

We perform a full angular fit to $B \to \psi K^*$ for the first time.
We use the amplitudes (four independent parameters):

- A_0, $A_{\|}$ (combinations of S- and D-wave; CP-even)
- $A_{\perp}$ (P-wave; CP-odd)

Relative phases among the A imply FSI, which imply non-factorizable contributions.

The decay requires three angles to fully specify,
We use the "transversity angle" basis.

Assuming factorization, one can predict
$\Gamma_L/\Gamma = |A_0|^2$ and $R \equiv \mathcal{B}(B \to \psi K^*)/\mathcal{B}(B \to \psi K)$
Previous results have been somewhat inconsistent/imprecise.

$B \to \psi K^{(*)}$ Analysis

Lepton ID cuts:

- e ID with E/p and dE/dx
- μ ID with penetration into muon system.

K (K^*) modes require one (both) lepton(s) to be identified.

The ψ mass cuts are

- -150 MeV/c^2 $< m_{ee} - m_\psi <$ 45 Mev/c^2
- -45 MeV/c^2 $< m_{\mu\mu} - m_\psi <$ 45 Mev/c^2

A kinematic fit improves the E_ψ resolution by $5-6\times$.

All angular resolutions ≤ 0.06 rad

We use $K^{*+} \to K^+\pi^0, K_S\pi^+$; $\quad K^{*0} \to K^+\pi^-, K_S\pi^0$

and require K^* mass within 75 Mev/c^2 of nominal.

Feed-across among K^* modes is suppressed with a decay angle cut.

The B is fully reconstructed.

We cut on $\Delta E \equiv |E_{cand} - E_{beam}| < 30 - 60$ MeV ($\sim 3\sigma$, mode-dep't)

Efficiencies range from 9% to 48%.

The ψK^* fit is made to M_B and the three angles.

K^* Mass

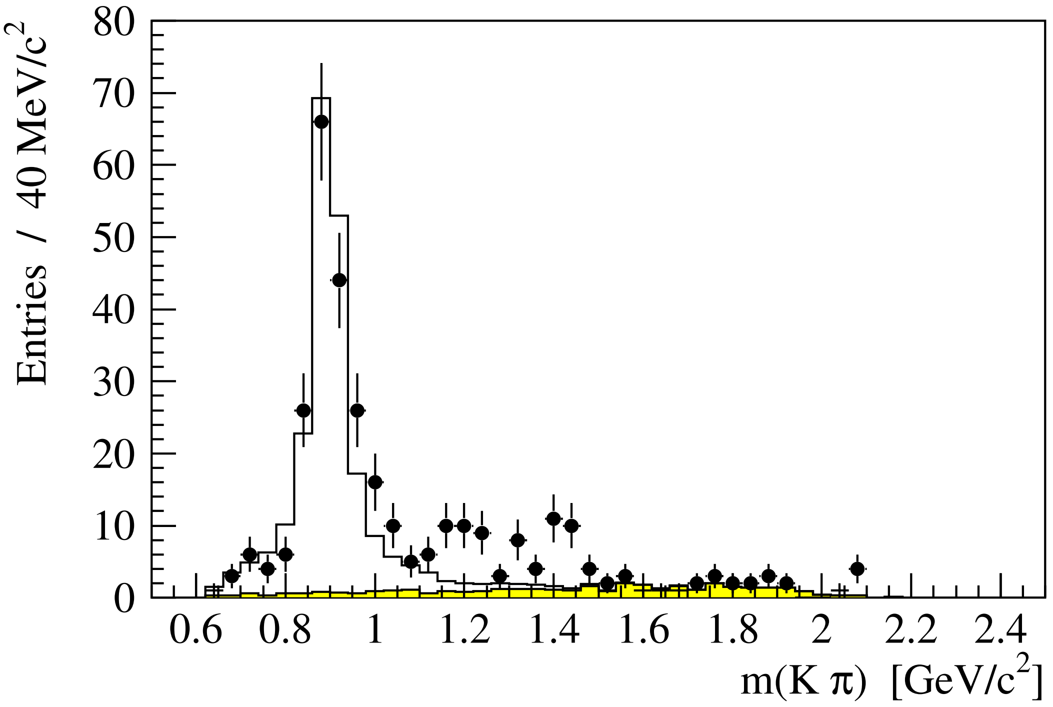

Figure 1: The $K\pi$ mass distribution for $m_B > 5.27\,\mathrm{GeV}/c^2$.
Empty histogram: $K^*(892)$ mass from fit (incl. feed-across)
Shaded histogram: combinatorial background

There is an excess of data above the $K^*(892)$.
We cannot yet distinguish resonances from non-resonant $K\pi$.
A conservative systematic error is used to allow for events under the K^* peak from this effect.

Projections of the ψK^* Angular Fit

(Angular plots are acceptance-corrected.)

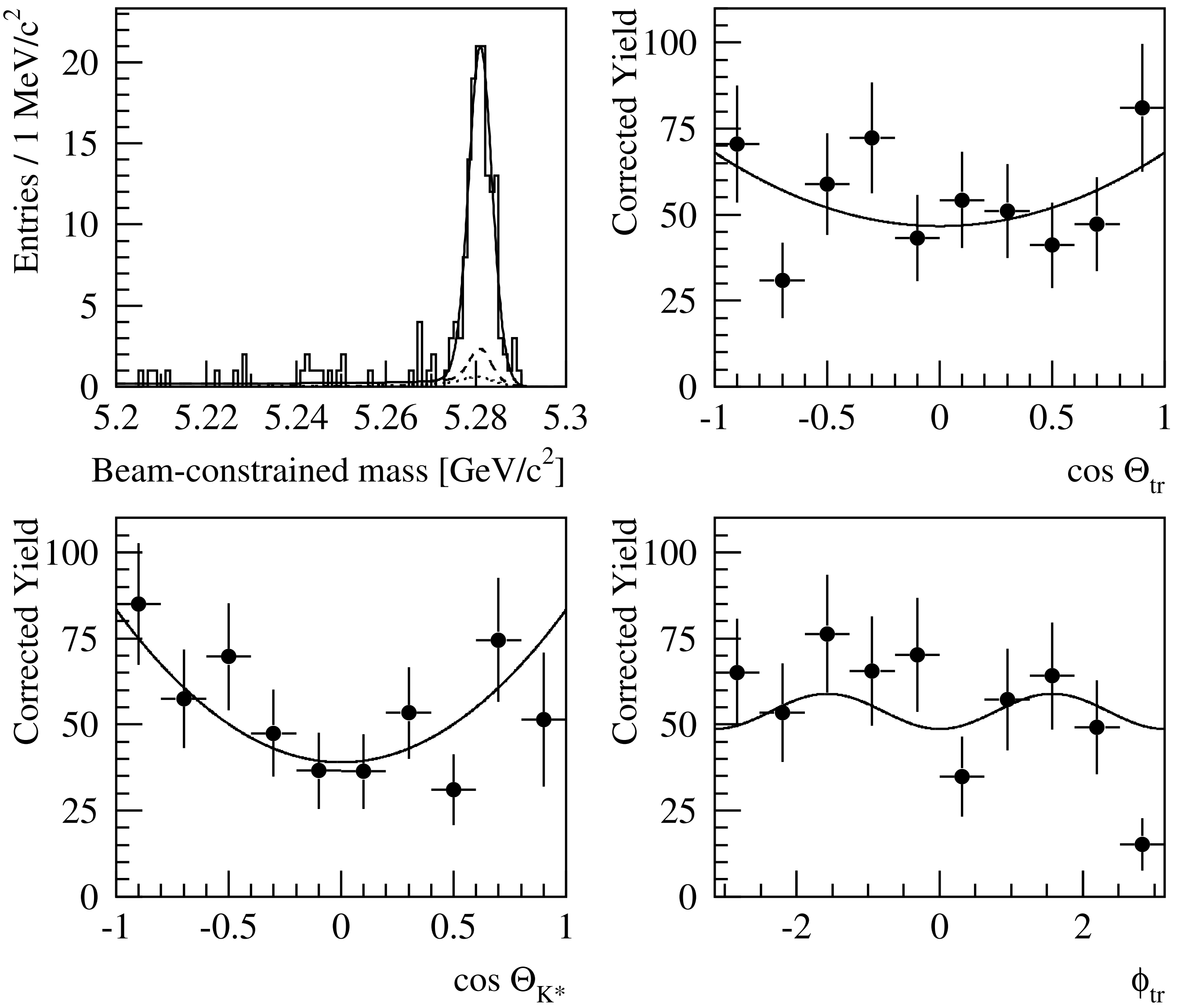

Figure 2: One-dimensional projections of the full 4-D fit.
The mass plot shows the data (histogram), the fit (solid line), the sum of all backgrounds (dashed) and the feed-across (dotted).

Beam-Constrained B Mass

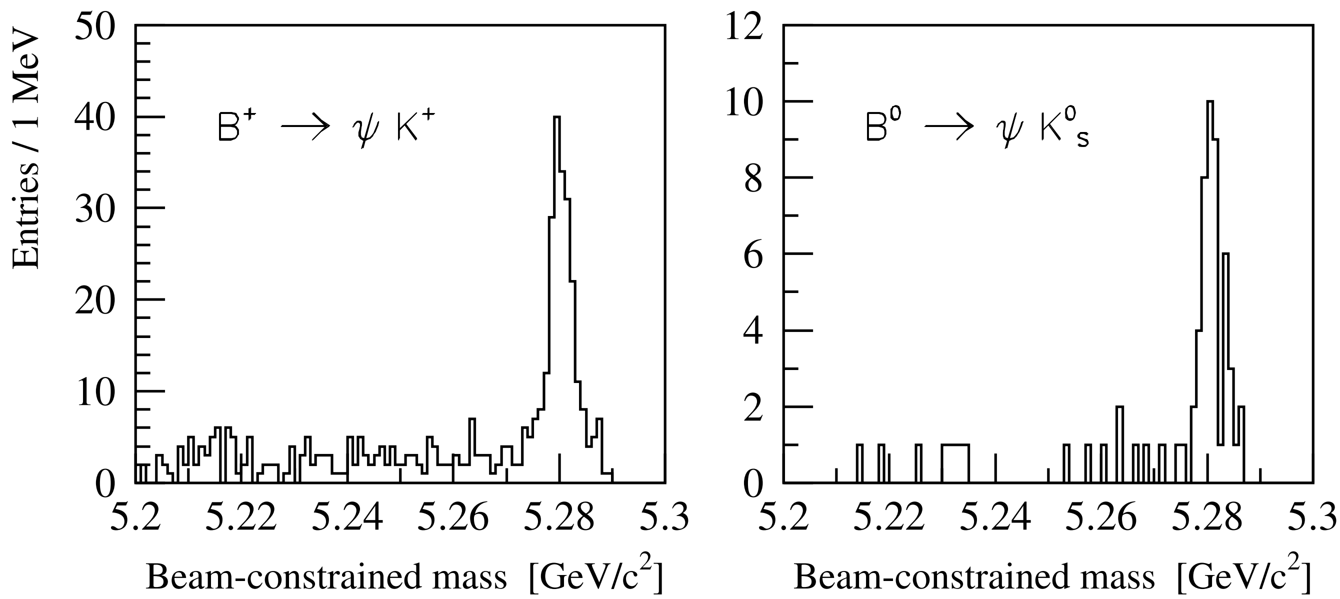

Figure 3: Beam-constrained mass distributions for $B^+ \to \psi K^+$ and $B^0 \to \psi K_S^0$.

Dominant systematics:

- K modes: tracking and particle ID efficiency, and $\mathcal{B}(\psi \to \ell\ell)$.
- K^* modes: feed-across between modes and non-res. $K\pi$.

$B \to \psi K^{(*)}$ Results

Table 1: Results of the ψK^* angular fit.

Parameter	Value
$\lvert A_0\rvert^2 = \Gamma_L / \Gamma$	$0.52 \pm 0.07 \pm 0.04$
$\lvert A_\perp\rvert^2 = \lvert P\rvert^2$	$0.16 \pm 0.08 \pm 0.04$
$\phi(A_\perp)$	$-0.11 \pm 0.46 \pm 0.03$ radian
$\phi(A_\parallel)$	$3.00 \pm 0.37 \pm 0.04$ radian

$\longrightarrow$ Small $\lvert P\rvert^2$ is good news for CP studies.

$\longrightarrow$ $\lvert A\rvert$ ~real, no sign of large FSI yet.

Table 2: Measured signal yields and branching fractions.

Decay mode	Signal Yield	Branching Fraction $[10^{-3}]$
$B^+ \to \psi K^+$	198.1 ± 14.9	$1.02 \pm 0.08 \pm 0.07$
$B^0 \to \psi K^0$	$45.5\,^{+7.3}_{-6.6}$	$0.85\,^{+0.14}_{-0.12} \pm 0.06$
$B^+ \to \psi K^{*+}$	42.5 ± 7.1	$1.41 \pm 0.23 \pm 0.24$
$B^0 \to \psi K^{*0}$	81.6 ± 10.3	$1.32 \pm 0.17 \pm 0.17$

We also extract: $R = \frac{\mathcal{B}(B\to\psi K^*)}{\mathcal{B}(B\to\psi K)} = 1.45 \pm 0.20 \pm 0.17$.

Γ_L/Γ and R are now in better agreement with naive factorization.

Assuming $\Gamma(B^+ \to \psi K^{(*)+}) = \Gamma(B^0 \to \psi K^{(*)0})$,
we get $(f_{+-}\tau_{B^+})/(f_{00}\tau_{B^0}) = 1.15 \pm 0.17 \pm 0.06.$

$B \to D^{(*)+}D^{(*)-}$ Analysis

$D^{(*)+}D^{(*)-}$ may have sensitivity to β comparable to ψK_S.
Expected $\mathcal{B} \sim \mathcal{O}(10^{-3})$.

The analysis:

- Event shape for continuum suppression.
- Track quality cuts; particle ID from dE/dx, TOF
- Dalitz weight cut for $K^-\pi^+\pi^0$.
- Kinematic fit to improve $M_{D^*} - M_D$
- Helicity angle cut for the π from D^* in D^*D mode.
- Cut on $\sum \chi^2$ from masses, mass diff's

Cuts tuned to give low prob. of bkg. fluctuating to expected signal.

We use the decay modes: $D^{*+} \to D^0\pi^+$.
$D^+ \to K^-\pi^+\pi^+; \quad D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^-\pi^+\pi^+$

2σ cuts are placed on ΔE and M_B.

The background is estimated from ΔE sidebands.

$B \to D^{(*)+} D^{(*)-}$ **Results**

In $D^{*+} D^{*-}$, we observe one event with an expected background of 0.022 ± 0.011 events. We quote the result as an upper limit; however, the event is "golden".

The other modes are consistent with expectations from background.

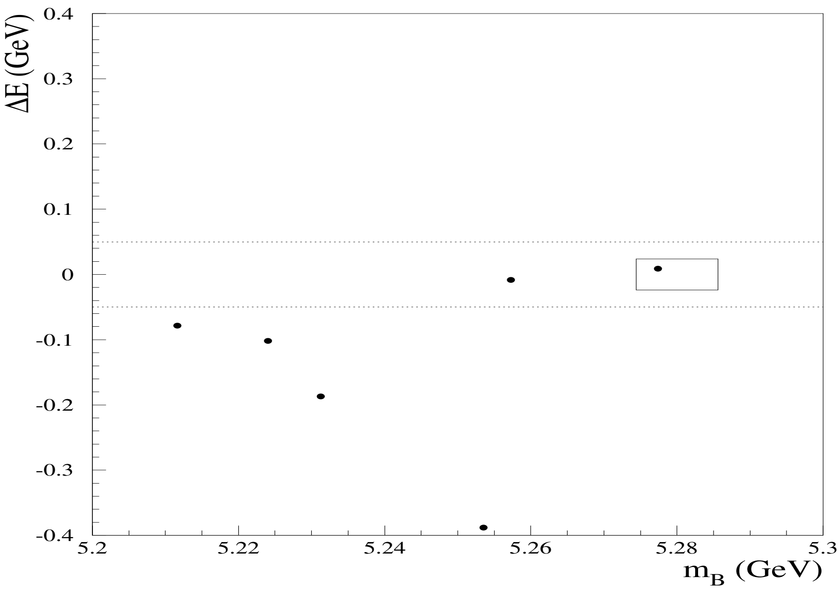

Figure 4: B-mass - ΔE distributions for $B^0 \to D^{*+} D^{*-}$.

$$\mathcal{B}(B^0 \to D^{*+} D^{*-}) < 2.2 \times 10^{-3} \quad 90\% \, CL$$
$$\mathcal{B}(B^0 \to D^{*+} D^{*+} + D^+ D^{*-}) < 1.8 \times 10^{-3} \quad 90\% \, CL$$
$$\mathcal{B}(B^0 \to D^+ D^-) < 1.2 \times 10^{-3} \quad 90\% \, CL$$

$\mathcal{B}(B \to D^{(*)}X)$ Analysis

Measurement of $\mathcal{B}(B \to D^{(*)}X)$ is an important input for charm-counting – an accounting of how b quarks decay.

We use the decay modes:
$D^0 \to K^-\pi^+$; $\quad D^+ \to K^-\pi^+\pi^+$;
$D^{*+} \to D^0\pi^+$; $\quad D^{*0} \to D^0\pi^+, D^+\pi^0$.

We use CLEO branching ratios for these modes.

The analysis cuts are simple:
- Event shape cuts suppress continuum.
- Track quality cuts are imposed.
- Loose dE/dx is used for particle ID.
- γ's are required to be in a good fiducial region, with $E_\gamma > 30MeV$.

The D^+ channel has background from D_s^+
- small effect: included in the fits via Monte-Carlo.

For the D^0 analysis, we take care in treating:
- $K - \pi$ swapping (broadens mass)
- K^+K^-, $\pi^+\pi^-$, $K^-\pi^+\pi^0$ (satellite peaks in mass)

D^0 result cross-checked by analysis with tighter particle ID cuts (which removed the bulk of these troubles).

$B \to D^0 X$ Mass Peaks

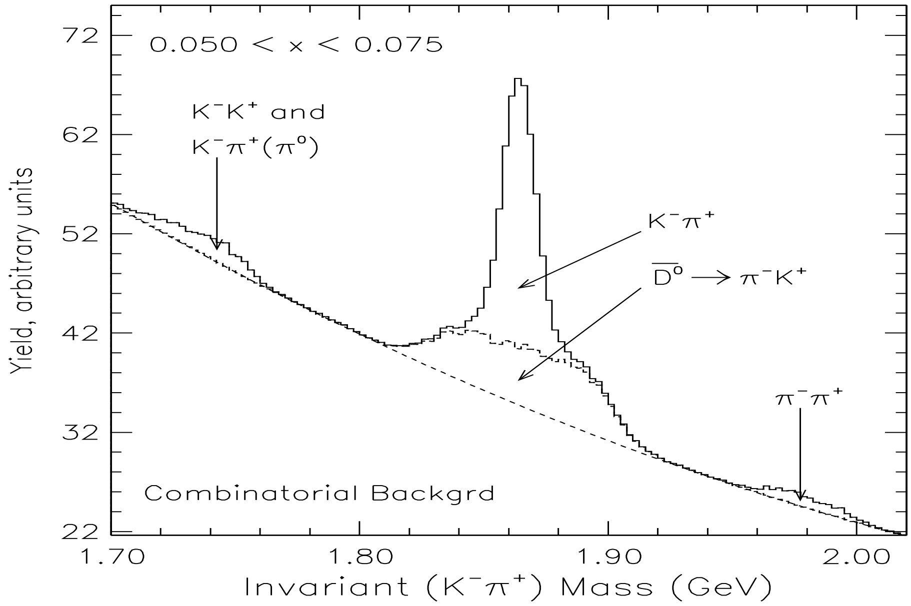

Figure 5: Low-momentum $K\pi$ Mass showing components.

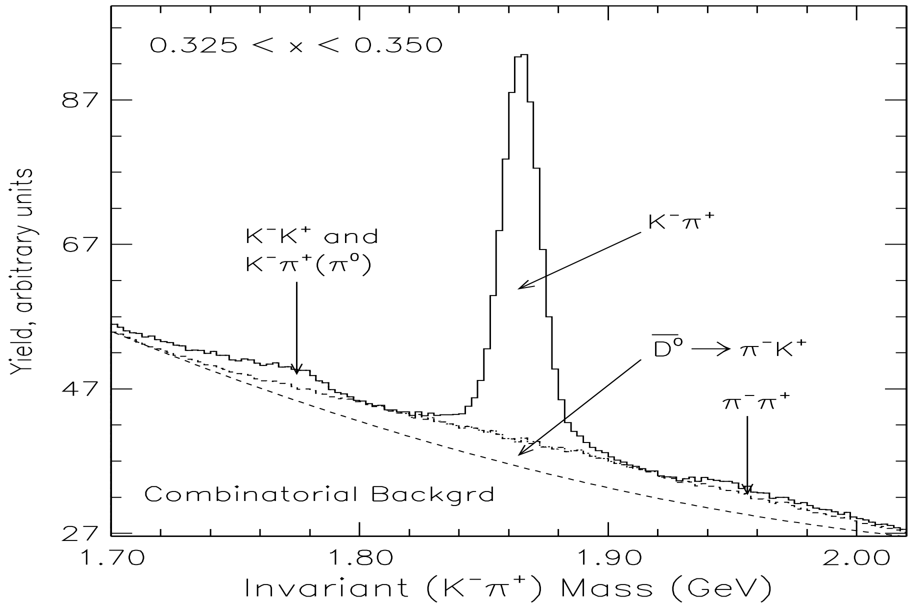

Figure 6: High-momentum $K\pi$ Mass showing components.

$\mathcal{B}(B \to DX)$ **Results**

Mass peaks fit for each momentum bin;
sum acceptance-corrected yields.
Much work to assure unbiased fits.

Total number of B's determined from luminosity and our measured $\Upsilon(4s)$ cross-section.

We measure the branching ratios:

- $\mathcal{B}(B \to D^0 X) = 0.636 \pm 0.014 \pm 0.019 \pm 0.018$
- $\mathcal{B}(B \to D^+ X) = 0.235 \pm 0.009 \pm 0.009 \pm 0.024$
- $\mathcal{B}(B \to D^{*0} X) = 0.247 \pm 0.012 \pm 0.018 \pm 0.018$
- $\mathcal{B}(B \to D^{*+} X) = 0.239 \pm 0.011 \pm 0.014 \pm 0.009$

The errors are statistics, systematics, and $D^{(*)}$ branching ratio, respectively.

We find a D^{*0}/D^{*+} ratio consistent with isospin:
$\mathcal{B}(B \to D^{*0} X)/\mathcal{B}(B \to D^{*+} X) = 1.03 \pm 0.07 \pm 0.09 \pm 0.08$

We also measured the momentum spectrum for each $D^{(*)}$ species, and the D^* polarization as a function of momentum.

Conventional Charm Counting

It is interesting to sum inclusive modes with charm.
$\rightarrow$ calculate n_c, the number of $c + \bar{c}$ quarks per b decay.

There has been a shortfall in n_c for some time.
Given $\mathcal{B}(B \rightarrow X\ell\nu)$, one expects $n_c \simeq 1.3$.
One cannot easily explain both n_c and $\mathcal{B}(B \rightarrow X\ell\nu)$.
(This has sparked interest in $b \rightarrow c\bar{c}s$ hadronization.)

Our $\mathcal{B}(B \rightarrow DX)$ results are a big improvement over the PDG.
But the shortfall persists.

Flavor-Tagging and "Upper-Vertex" Charm

Using D-ℓ correlations, CLEO has measured (Moriond '96):

$$\mathcal{B}(B \rightarrow DX) = (8.1 \pm 2.6)\% \qquad (D, \textit{not } \bar{D})$$

The lepton tags one B;
the angular correlation tells if D and ℓ are from same B.

We can now look at flavor-tagged charm yields for the first time.
This is a powerful new tool!

Charm Counting

Table 3: Input Values for Charm Counting.

Mode	Rate	Comment
$D^{0,+}\,X$	0.871 ± 0.035	New CLEO
$D_s\,X$	0.118 ± 0.031	CLEOII $D_s X$ + $\mathcal{B}(D_s \to \phi\pi)$
$\Lambda_c\,X$	0.039 ± 0.020	unpublished
$\Xi_c^+\,X$	0.008 ± 0.005	corrected
$\Xi_c^0\,X$	0.012 ± 0.009	corrected
$2 \times c\bar{c}\,X$	0.054 ± 0.007	η_c limit
SUM	1.102 ± 0.052	

We use CLEO's latest $\mathcal{B}(B \to D_s X)$ and our new, model-independent $\mathcal{B}(D_s \to \phi\pi) = (3.6 \pm 0.9)\%$.

We use an unpublished CLEO thesis result and the world average $\mathcal{B}(\Lambda_c \to pK\pi)$.

Ξ_c corrected for $\Gamma(\Xi_c \to X\ell\nu)/\Gamma(D \to X\ell\nu) \simeq 2.5 \pm 1.0$, which was originally taken as 1.

We also take $\Gamma(\Xi_c \to \Xi\ell\nu)/\Gamma(\Xi_c \to X\ell\nu) \simeq 1.0 \pm 0.2$.

We take the upper limit for $\eta_c X$ as the sum of all unmeasured charmonium modes.

Flavor-Tagged Charm Counting

(c.f. recent preprint by Dunietz, et al.; [hep-ph/961242])

They calculate $\mathcal{B}(b \to \mathrm{no\,open\,charm})$ in two ways:

- Count c in $b \to c$. (Method A)
- Count $\bar{c}$ in $b \to c\bar{c}s$. (Method B)

("open charm" = a particle with $C = \pm 1$.)

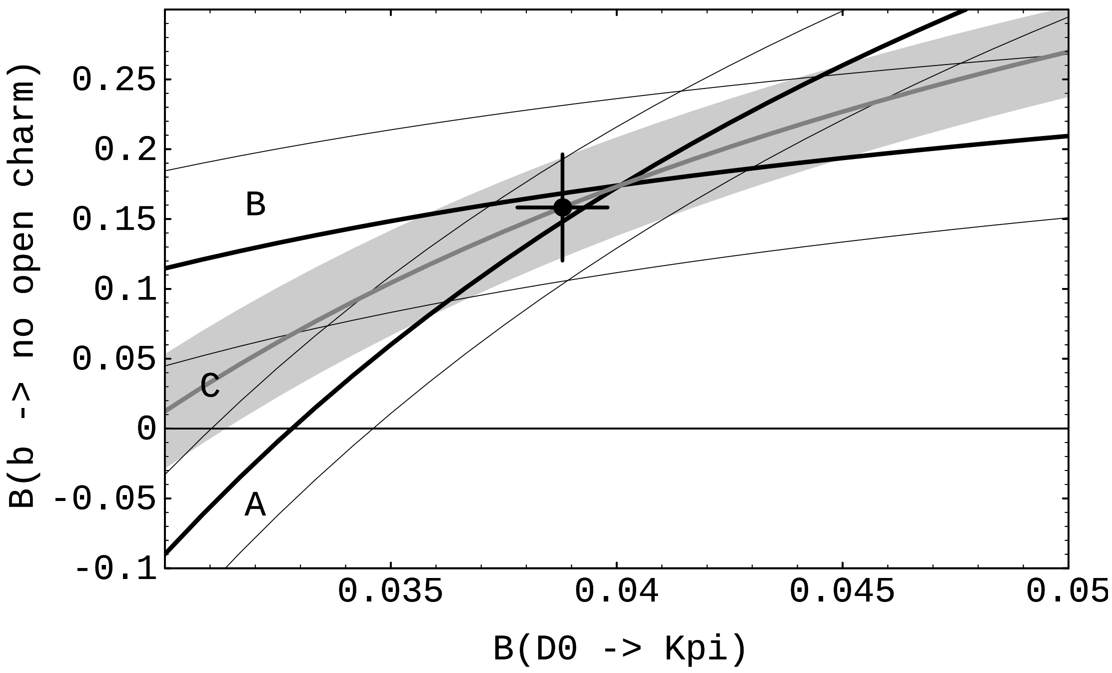

Figure 7: Flavor-specific counting. (courtesy Dunietz, et al.)

This particular study shows that:

- Methods are self-consistent with "conventional" $\mathcal{B}(D^0 \to K^-\pi^+)$.
- Implies a much larger that expected $\mathcal{B}(b \to \mathrm{no\,open\,charm})$.

Different input assumptions may yield other conclusions.

Real point: The data exists to do such studies!

Related Pursuits for the Near Future

- New CLEO2.5 Data for $\psi K^{(*)}$ and $D^{(*)+}D^{(*)-}$ Studies.
- New Check of $\mathcal{B}(D^0 \to K^-\pi^+)$.
- Update/Extend $D - \ell$ Correlations (flavor-tagged inclusive).
- Measure $\mathcal{B}(B \to D_{s1}X)$.
- Look for Exclusive $\bar{B} \to D^{(*)}\bar{D}^{(*)}\bar{K}^{(*)}$.
- Also, updates of $D^{(*)}\pi^{(*)}$ modes.
- ...and many more!!!

Conclusions

- $\psi K^{(*)}$ and $D^{(*)+}D^{(*)-}$ interesting for CP-violation studies
- Charm counting is still interesting and puzzling.
- Flavor-tagged information can give new insights.
- Lots of interest is focused on the $b \to c\bar{c}s$ transition.
- CLEO is contributing on all fronts.

Curious? Here's the status of R and Γ_L/Γ

CLEO:

$$R = \mathcal{B}(B \to \psi K^*)/\mathcal{B}(B \to \psi K) = 1.45 \pm 0.20 \pm 0.17\,.$$

CDF: (FERMILAB-PUB-96-119-E)

$$R = \mathcal{B}(B \to \psi K^*)/\mathcal{B}(B \to \psi K) = 1.53 \pm 0.31 \pm 0.09\,.$$

Γ_L/Γ experimental:

$$\begin{array}{rll} \text{ARGUS} & (1994): & 0.97 \pm 0.16 \pm 0.15 \\ \text{CLEOII} & (1994): & 0.80 \pm 0.08 \pm 0.05 \\ \text{CDF} & (1995): & 0.65 \pm 0.10 \pm 0.04 \\ \text{CLEOII} & (1996): & 0.52 \pm 0.07 \pm 0.04 \end{array}$$

Table 4: R and Γ_L/Γ Theory

Model	R	Γ_L/Γ
BSW	4.2	0.57
Neubert, et al.	1.61	0.36
Aleksan, et al. *	2.15	0.45
Gourdin, et al.		$0.45^{+0.13}_{-0.17}$
Chang, Tseng	1.84	0.56

* = from a fit to CDF data.