Some CLEO Results on B and Charm

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for the CLEO Collaboration

Outline:

- B Physics
  - Observation of $B \to \phi K$ and $B \to \phi K^*$ hep-ex/0101032
  - New limit on $\mathcal{B}(B \to \pi^\circ \pi^\circ)$
  - $\mathcal{B}(b \to s\gamma)$, the γ spectrum and $|\mathrm{V}_{ub}|$
  - Limit on CP asymmetry in $B^\circ \overline{B}^\circ \to \ell^\pm \ell^\pm$ hep-ex/0101006
- Charm Physics
  - Some new results on D° mixing CP violation and DCSD hep-ex/0102006, hep-ex/0012054
  - First measurement of $\Gamma(D^{*+})$ hep-ex/0102007
  - $\Lambda_c \overline{\Lambda}_c$ correlations in $e^+e^- \to c\bar{c}$ hep-ex/0101051
- Omitted: 13 out of 21 papers since after ICHEP 2000.

CLEO II and CLEO II.V

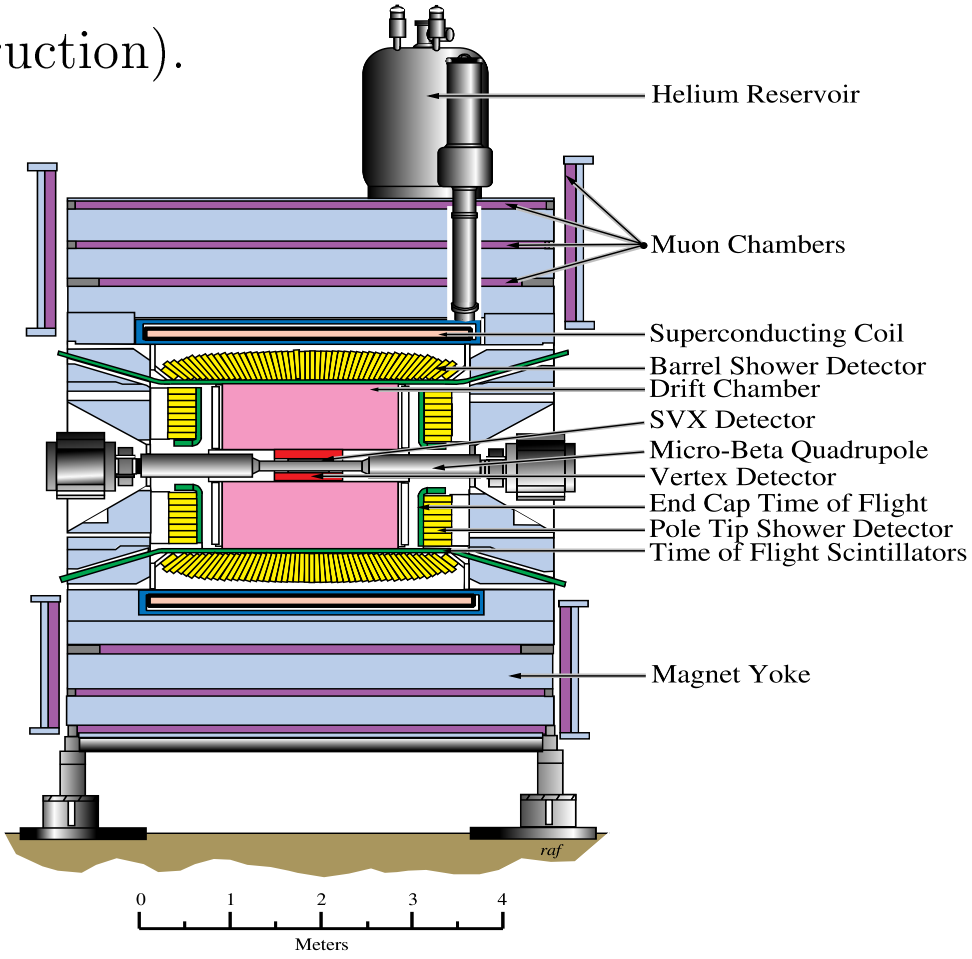
- Excellent E.M. shower calorimeter (photon, π°detection, electron ID).
- Hermeticity (neutrino reconstruction).

Nov. 1990 to Feb. 1999:

- 13.8 fb^{-1} of data:
- 9.74 M $e^+e^-\to B\overline{B}$
- 16.8 M $e^+e^- \to c\bar{c}$
- 12.6 M $e^+e^- \to \tau^+\tau^-$

CLEO III:

- $\sim 4.6 fb^{-1}$ since July 2000.
- Best $\mathcal{L} = 1.2 \times 10^{33} cm^{-2}/s$



$B \to \phi K$ AND $B \to \phi K^*$

Clear signature for gluonic penguin.

Can be used the measure $\sin 2\beta$.

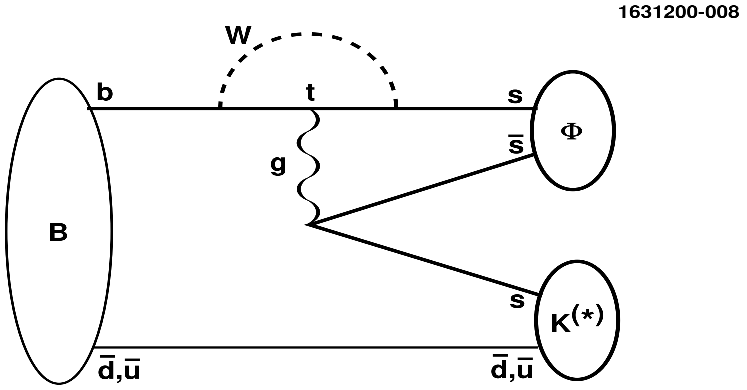
Sensitive to V_{ts}.

Topologies used: ϕK^-, ϕK°_S, ϕK^*,
with $K^\circ_S \to \pi^+\pi^-$, $\phi \to K^+K^-$
and $K^* \to (K^-\pi^+,\ K^\circ_S\pi^\circ,\ K^-\pi^\circ,\ K^\circ_S\pi^-)$.

Use beam-constrained candidate B mass:
$M_B \equiv \sqrt{E_{beam}^2 - p_B^2}$ and
$\Delta E \equiv E_1 + E_2 - E_{beam}$, $|\Delta E| < 200\text{MeV}$

$e^+e^- \to q\bar{q}$ backgr. suppression: $H_2/H_0 < 0.6$

Separate unbinned Maximum Likelihood fit for each topology using:
M_B, ΔE, M_ϕ,
$p_B \cdot beam$, (thrust B)$\cdot$(thrust remainder);
when applicable:
helicity angle, M_{K^*}, S_K (dE/dx information),



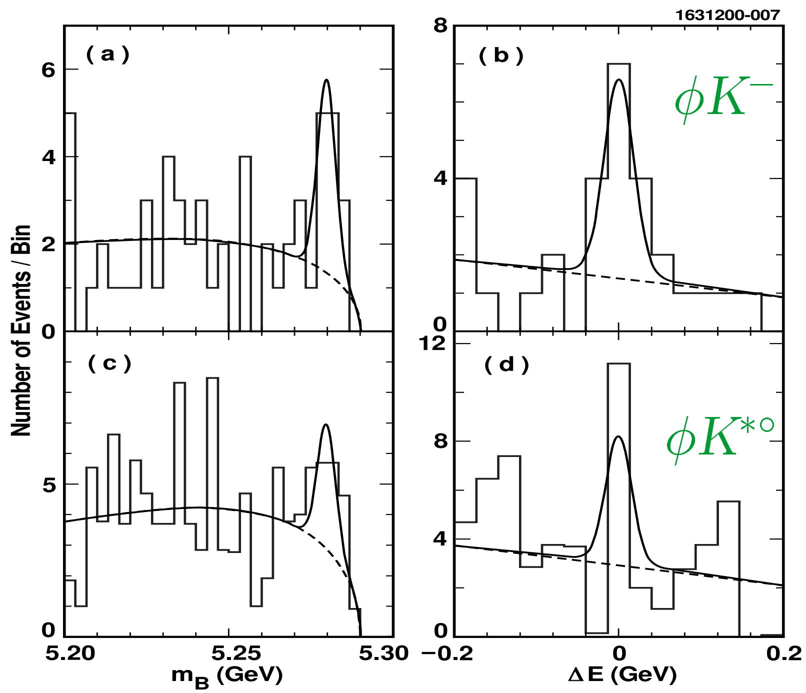


Table 1: **Results**

Mode	Yield	$\mathcal{E}(\%)$	$\mathcal{B}_{fit}$ $\times 10^6$	Statist. Signif.	$\mathcal{B}$ $\times 10^6$	Theor. $\mathcal{B}$ $\times 10^6$
ϕK^-	$14.2^{+5.5}_{-4.5}$	54	$5.5^{+2.1}_{-1.8} \pm 0.6$	5.4σ	see $\mathcal{B}_{fit}$	0.7-16
ϕK^0	$4.2^{+2.9}_{-2.1}$	48	$5.4^{+3.7}_{-2.7} \pm 0.7$	2.9σ	< 12.3	0.7-13
ϕK comb.	—	—	—	6.1σ	$5.5^{+1.8}_{-1.5} \pm 0.7$	
ϕK^{*0} $(K^-\pi^+)$	$12.1^{+5.3}_{-4.3}$	38	$9.9^{+4.3+1.6}_{-3.5-1.6}$	4.5σ	—	
ϕK^{*0} $(K^0\pi^0)$	$5.1^{+3.9}_{-2.8}$	20	$46.3^{+35.7+5.9}_{-26.0-6.6}$	2.7σ	—	
ϕK^{*0}	—	—	$11.5^{+4.5+1.8}_{-3.7-1.7}$	5.1σ	see $\mathcal{B}_{fit}$	0.2-31
ϕK^{*-} $(K^-\pi^0)$	$3.8^{+4.1}_{-2.8}$	25	$9.3^{+10.1+1.7}_{-7.0\ -1.5}$	1.5σ	—	
ϕK^{*-} $(K^0\pi^-)$	$4.0^{+3.1}_{-2.2}$	32	$11.4^{+9.0+1.8}_{-6.3-1.8}$	2.7σ	—	
ϕK^{*-}	—	—	$10.6^{+6.4+1.8}_{-4.9-1.6}$	3.1σ	< 22.5	0.2-31
ϕK^* comb.	—	—	—	5.9σ	$11.2^{+3.6+1.8}_{-3.1-1.7}$	

In summary, we have measured $\mathcal{B}(B^-\to\phi K^-) = (5.5^{+2.1}_{-1.8} \pm 0.6) \times 10^{-6}$

and $\mathcal{B}(B^0\to\phi K^{*0}) = (11.5^{+4.5+1.8}_{-3.7-1.7}) \times 10^{-6}$

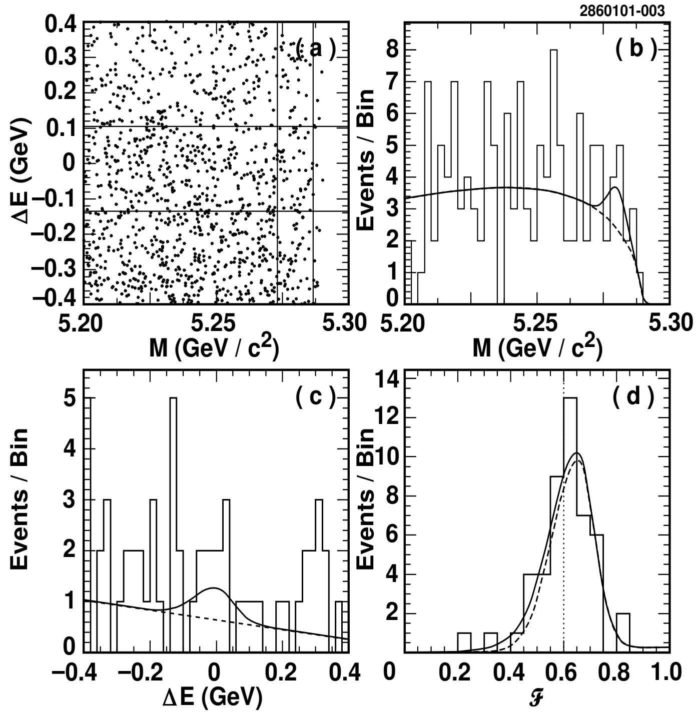
each with statistical significance above 5σ. Our results will help constrain model parameters.

New limit on $\mathcal{B}(B^o \to \pi^\circ\pi^\circ)$

CP asymmetry in $B \to \pi^+\pi^-$ gives sum $(\beta + \gamma)$ of phases of CKM elements V_{td}^* and V_{ub}^*,
when combined with $\mathcal{B}(B^+ \to \pi^+\pi^\circ)$ and $\mathcal{B}(B^o \to \pi^\circ\pi^\circ)$ in an isospin analysis to get relative phase of tree and penguin contributions (Gronau & London, PRL **65** (1990) 3381).

We produced a stringent upper limit on $\mathcal{B}(B^o \to \pi^\circ\pi^\circ)$.

Resolution: $M_B = 3.4$ MeV, $\Delta E \cong 60$ MeV.
Signal region: $5.2 \leq M_B \leq 5.3$, $|\Delta E| < 0.4$ MeV.
Main background from $e^+e^- \to q\bar{q}$, suppressed using event shapes.
$B^\pm \to \rho^\pm\pi^o$ background separated by ΔE.
Unbinned Maximum Likelihood fit using M_B, ΔE and the *Fisher Discriminant* (event shape)
finds $N_S = 6.2^{+4.8}_{-3.7}$: only 2σ significance.



Result: $\mathcal{B}(B^o \to \pi^\circ\pi^\circ) = (2.2^{+1.7}_{-1.3} \pm 0.7) \times 10^{-6}$

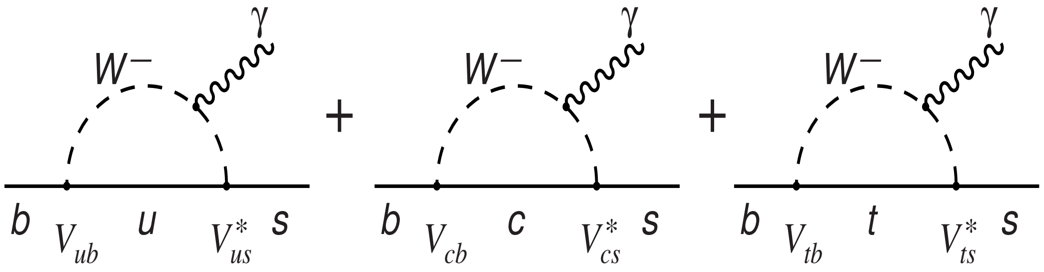
A series of Monte Carlo simulated experiments give 90% confidence level limits:

$\boxed{\mathcal{B}(B^o \to \pi^\circ\pi^\circ) < 5.7 \times 10^{-6}}$ PRELIMINARY

$\mathcal{B}(b \to s\gamma)$, the γ spectrum and $|V_{ub}|$

Interest, motivation:

- Pure electroweak penguin, no tree diagrams
- Sensitive to
  - $V_{ts}^* V_{tb}$
  - new physics particles in loop
  - anomalous WWγ coupling.



- γ spectrum allows a more precise extraction of $|V_{ub}|$ and $|V_{cb}|$ from B S.L. decays
- SM expectation:
  - $\mathcal{B}(b \to s\gamma) = (3.3 \pm 0.3) \times 10^{-4}$,
  - spectrum: $2.0 < E_\gamma < 2.7$ GeV.

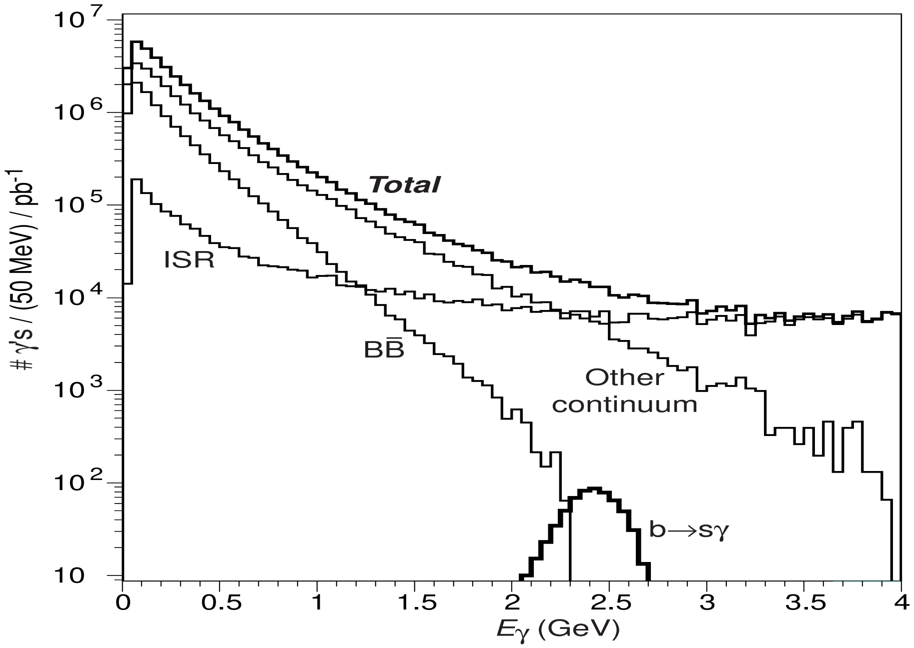
Challenge:

suppress the huge background from:

(i) Continuum I.S.R.

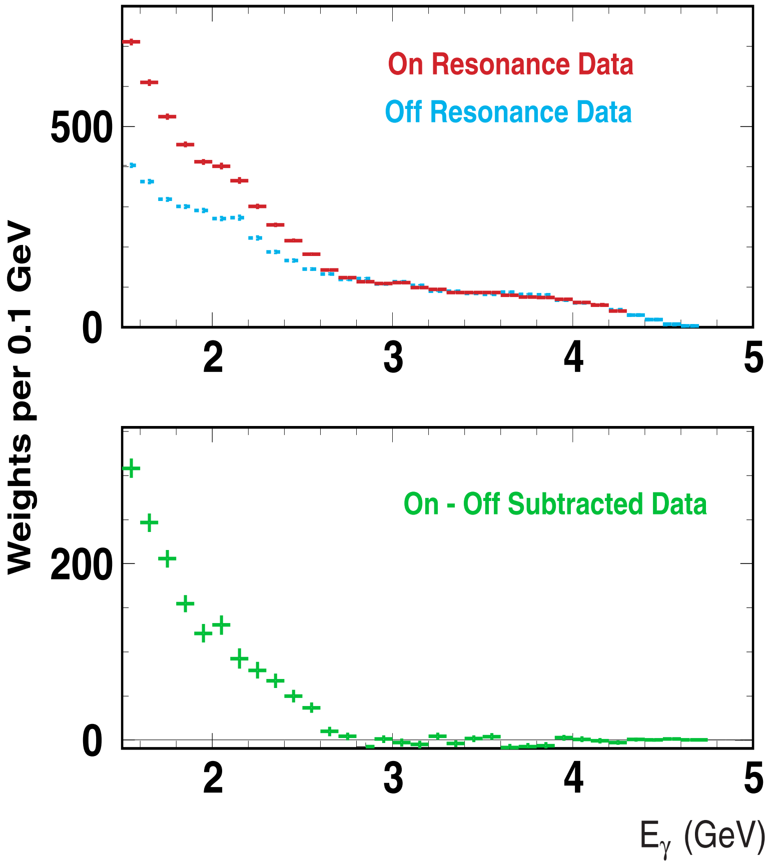
(ii) Continuum π°

(iii) Other B decays



Tools:

- Continuum suppression:
  - neural net of various shape variables,
  - "Pseudo-reconstruction": identify strange mesonic system, K+up to $4\pi(\leq 1\pi^\circ)$, combine it with γ to get the B candidate mass and ΔE.
  - χ^2 to select best combination.
  - Presence of high energy lepton (from other B).
  - Weight each event with combination of the above.
- $B\overline{B}$ background suppression:
  - veto π°, η,
  - adjust for π° detection efficiency.
- Subtract continuum spectrum from ON $\Upsilon(4S)$ data,
- Subtract $B\overline{B}$ background.



From MC simulation using Ali and Greub model: Efficiency=$(4.29 \pm 0.18)\%$

Results: PRELIMINARY

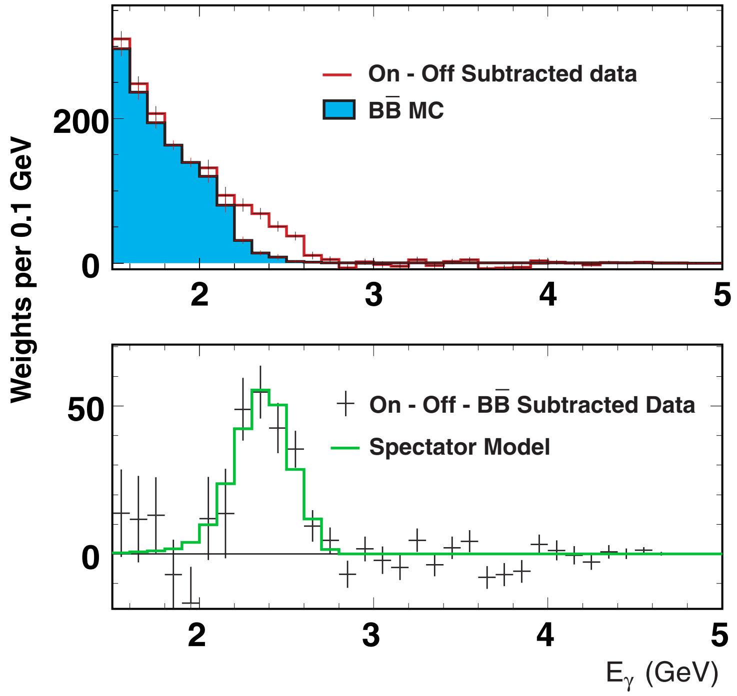
(i) $\mathcal{B}(b \to s\gamma) = (2.85 \pm 0.35 \pm 0.22) \times 10^{-4}$
consistent with SM prediction.

(ii) The γ spectrum itself and its moments:

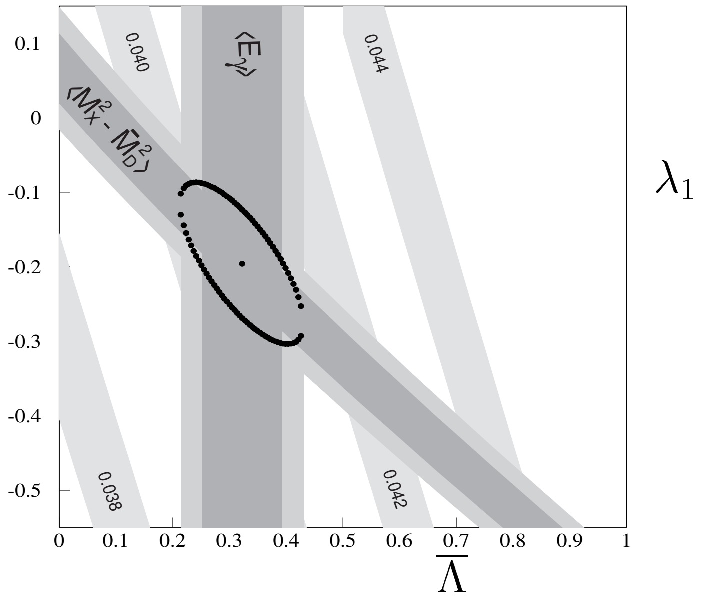
$$\langle E_\gamma \rangle = 2.36 \pm 0.027 \pm 0.014 \text{ GeV}$$

$$\langle E_\gamma^2 - \langle E_\gamma \rangle^2 \rangle = 0.018 \pm 0.006 \pm 0.003 \text{ GeV}^2$$

The moments determine HQET parameters λ_1, $\overline{\Lambda}$:
$\langle E_\gamma \rangle$ determines λ_1, $\langle E_\gamma^2 - \langle E_\gamma \rangle^2 \rangle$ determines $\overline{\Lambda}$.
λ_1 and $\overline{\Lambda}$ agree with values extracted from hadronic mass spectrum in B S.L. decay [CLEO 2001].



Knowledge of the γ spectrum reduces the theoretical uncertainty in the fraction of the lepton spectrum from $b \to u\ell\nu$ beyond the in $b \to c\ell\nu$ end-point [M. Neubert *et al.*].
It thus improves the extraction of $|V_{ub}|$ from the experimental data.
It also improves the extraction of $|V_{cb}|$ from $b \to c\ell\nu$.



Limit on CP asymmetry in $B^\circ\overline{B}^\circ \to \ell^\pm\ell^\pm$

SM predicts that the mixing rates $B^0 \to \bar{B}^0$ and $\bar{B}^0 \to B^0$ are very nearly equal.

In $\Upsilon(4S) \to B^0\bar{B}^0$ event, where both B mesons undergo semileptonic decay:

a large $$a_{\ell\ell} \equiv \frac{N(\ell^+\ell^+) - N(\ell^-\ell^-)}{N(\ell^+\ell^+) + N(\ell^-\ell^-)} = \frac{4\Re(\epsilon_B)}{1+|\epsilon_B|^2}$$ indicates CP Violation.

Problem: large number of correction terms.

Drastic reduction systematic error by combining measurement of $a_{\ell\ell}$ with that of the single lepton asymmetry a_ℓ.

Result: $a^0_{\ell\ell} = (+0.013 \pm 0.050 \pm 0.005)(1.00 \pm 0.10)$

that agreement with our recent measurement $a_{CP} = +0.017 \pm 0.070 \pm 0.014$ via partial hadron reconstruction [P.L. **B490** (2000) 36].

From weighted average of the two:

$$\frac{Re(\epsilon_B)}{1+|\epsilon_B|^2} = +0.0035 \pm 0.0103 \pm 0.0015\ .$$

We have found that, combining the asymmetry $a_{\ell\ell}$ with a_ℓ,
the systematic error is drastically reduced, and with enough statistics,
allows detection of an $a_{\ell\ell}$ asymmetry as low as 0.015.

Charm Physics

- More results on D° mixing and DCSD and CP violation
  - New limit of the mixing parameter $y_{CP} = \frac{\Delta\Gamma}{2\Gamma}$
  - New limits on CP asymmetries in $D^\circ \to K^+K^-$, $\pi^+\pi^-$, $K^\circ_S\pi^\circ$, $\pi^\circ\pi^\circ$, $K^\circ_S\pi^\circ$.
  - First measurement of the rate of wrong-sign $D^0 \to K^+\pi^-\pi^0$
- First measurement of $\Gamma(D^{*+})$
- $\Lambda_c\overline{\Lambda}_c$ correlations in $e^+e^- \to c\bar{c}$

Mixing and CP violation in D° decay: hunting grounds for New Physics:

SM predicts:

mixing amplitudes $(10^{-6} < |x|,\ |y| < 6 \times 10^{-2})$

CP violation asymmetries $\mathcal{O}(10^{-3})$.

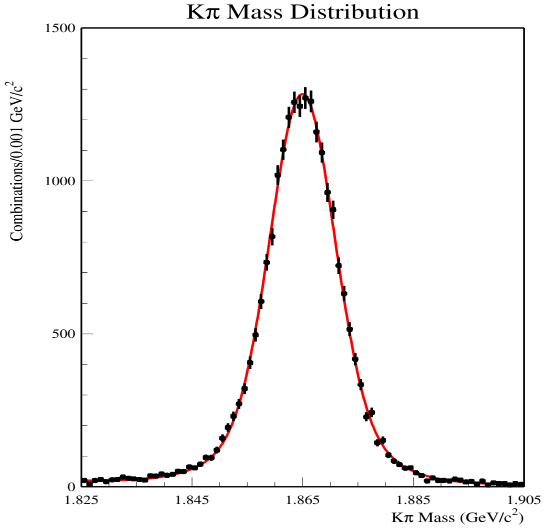
D_+,D_- Lifetime Difference and D°-$\overline{D}^\circ$ Mixing

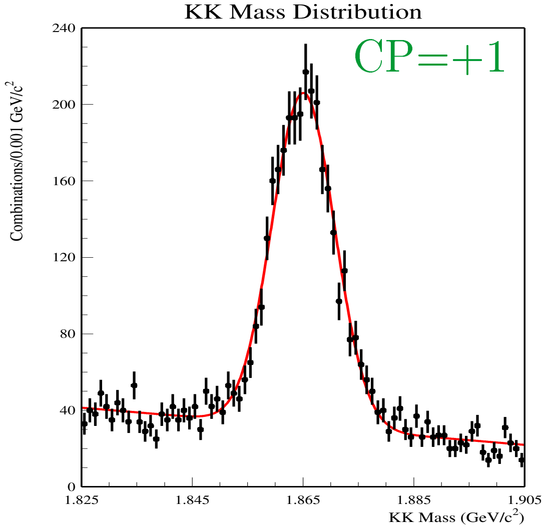
Neglect CP violation. The two D° CP eigenstates, D_+, D_- have (slightly) different decay rates: $\Gamma_\pm = \Gamma(1 \pm y)$ where Γ is the average of them and $y_{CP} = \Delta\Gamma/2\Gamma \ll 1$ is one of the two mixing parameters.

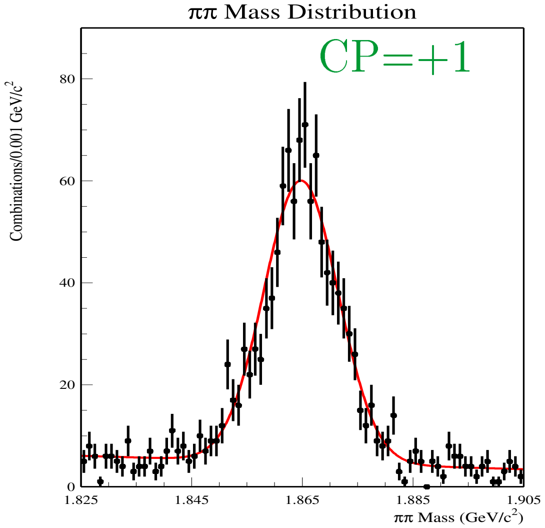
Then y can be obtained from the D° average lifetime $\overline{\tau}$ and the average lifetime τ_+ of the CP=+1 eigenstate,D_+:

$$y_{CP} = 1 - \frac{\overline{\tau}}{\tau_+}$$

Signal: 20272 ± 178 $D^\circ \to K^-\pi^+$ 2463 ± 65 $D^\circ \to K^-K^+$ 930 ± 37 $D^\circ \to \pi^+\pi^-$



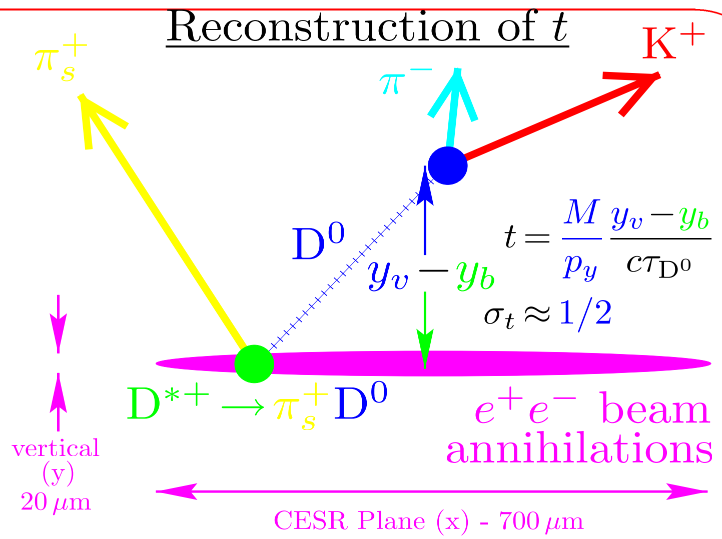


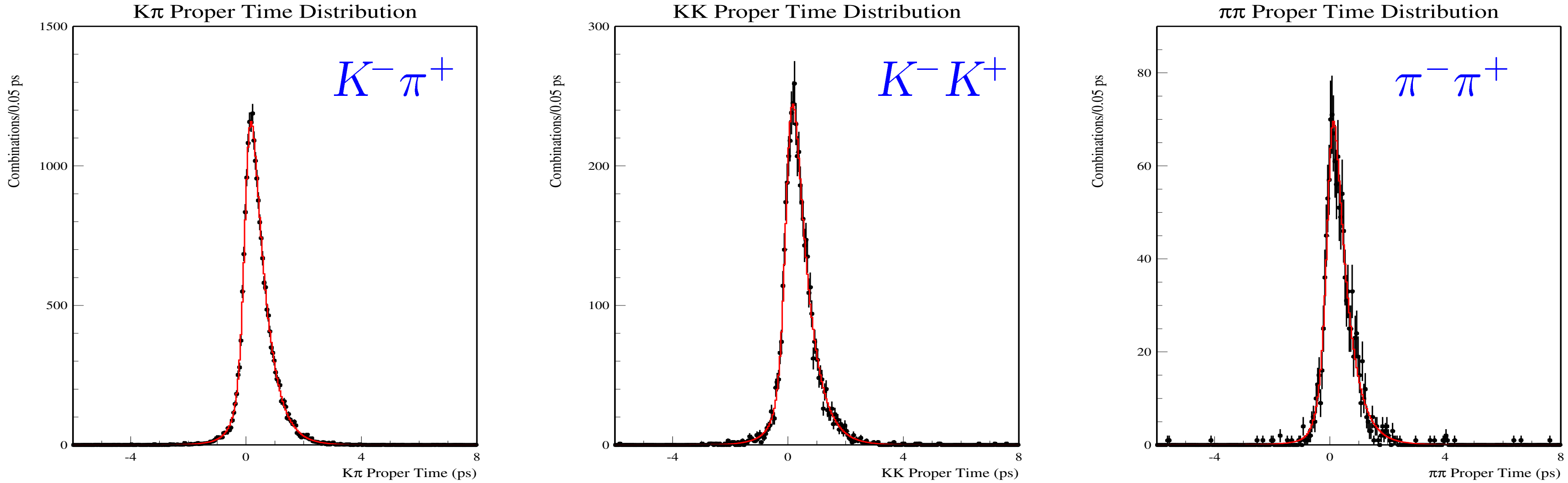


Parameterization of signal and two backgrounds is largely based on $K^-\pi^+$ sample.

Tagging and time of flight uses parent D^{*+}.

Vertexing and use of narrow luminous region ($\sigma_{vertical} = 7\ \mu$m), for accurate measurement of vertical component of decay distance ($\sim 40\mu$m).





$\overline{\tau} = 0.4046 \pm 0.0036$ ps $\qquad \tau_+ = 0.411 \pm 0.012$ ps $\qquad \tau_+ = 0.401 \pm 0.017$ ps

Results: $y_{KK} = -0.019 \pm 0.029 \pm 0.016$ and $y_{\pi\pi} = +0.005 \pm 0.043 \pm 0.018$.

Weighted average of y_{KK} and $y_{\pi\pi}$:

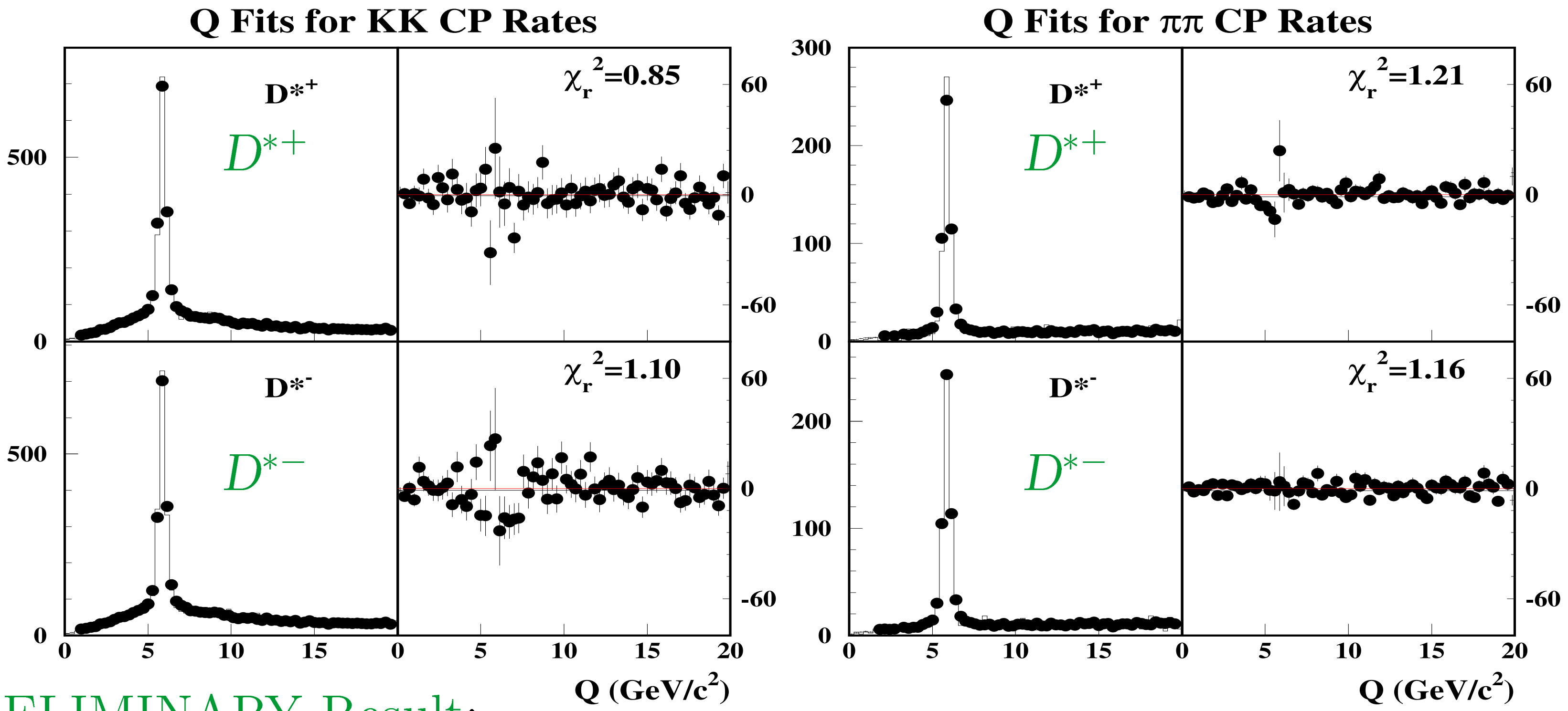
$$y_{CP} = -0.011 \pm 0.025(\text{stat}) \pm 0.014(\text{syst})\ (\text{PRELIMINARY}).$$

Limits on CP asymmetries in $D^\circ \to K^+K^-$, $\pi^+\pi^-$

Flavor tagging from parent D^{*+}. Final states: K^+K^-, $\pi^+\pi^-$

D° yield from fit of $Q \equiv M^* - M - m_\pi$ distributions.

Asymmetry we want to measure: $A = \frac{\Gamma(D^\circ \to f) - \Gamma(\overline{D}^\circ \to f)}{\Gamma(D^\circ \to f) + \Gamma(\overline{D}^\circ \to f)}$



PRELIMINARY Result:

$A(K^+K^-) = (0.05 \pm 2.2 \pm 0.8\ )\%$ $\qquad A(\pi^+\pi^-) = (2.0 \pm 3.22 \pm 0.8)\%.$

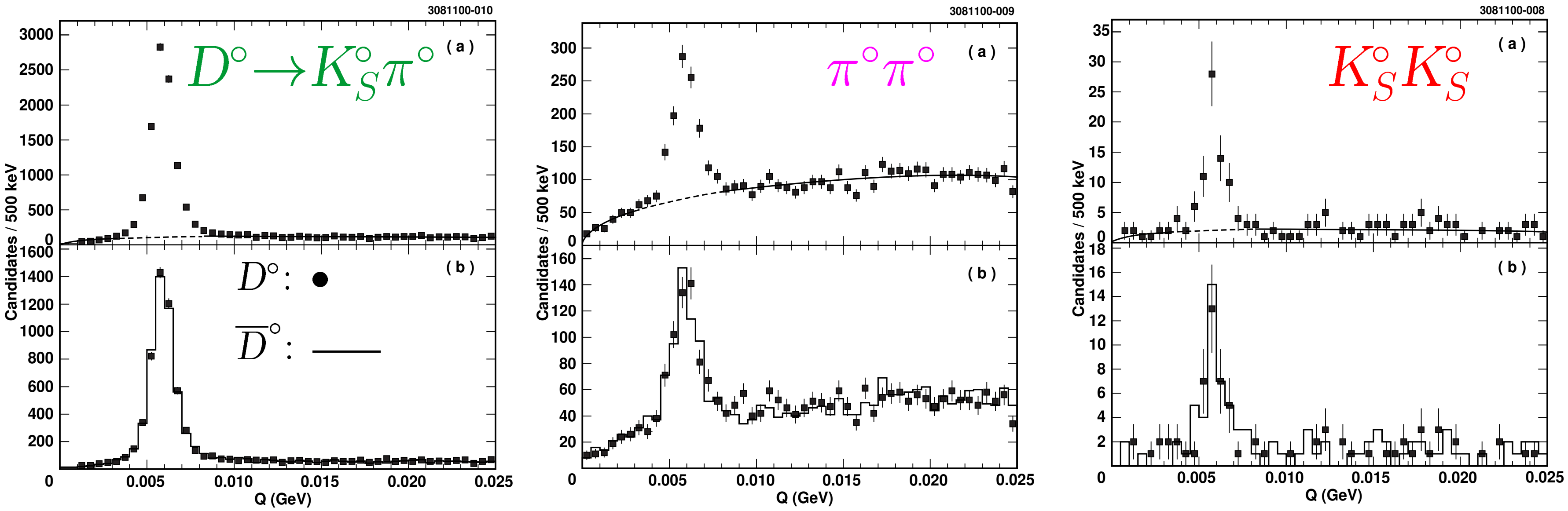
No CP asymmetry detected.

Limits on CP asymmetries in $D^\circ \to K_S^\circ \pi^\circ$, $\pi^\circ\pi^\circ$, $K_S^\circ K_S^\circ$

$K_S^\circ K_S^\circ$ case treated very similarly to K^+K^-, $\pi^+\pi^-$ case.

But in $K_S^\circ \pi^\circ$ and $\pi^\circ\pi^\circ$ case, vertex reconstruction is not possible.

However yield of D° and $\overline{D}^\circ$ can be found by D^{*+} energy release distribution.



Result:

$A(K_S^0\pi^0) = (+0.1 \pm 1.3)\%$, $A(\pi^0\pi^0) = (+0.1 \pm 4.8)\%$, $A(K_S^0 K_S^0) = (-23 \pm 19)\%$

where statistical and systematic errors are combined.

$A(\pi^0\pi^0)$ and $A(K_S^0 K_S^0)$ are first measurements,

$A(K_S^0\pi^0)$ is significant improvement over previous results.

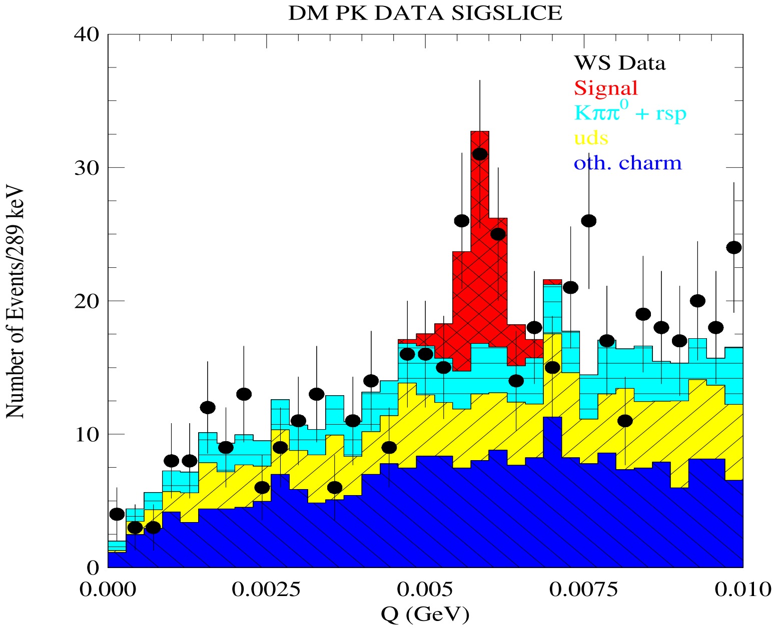
First Observation of Wrong-Sign $D^0 \to K^+\pi^-\pi^0$ Decay

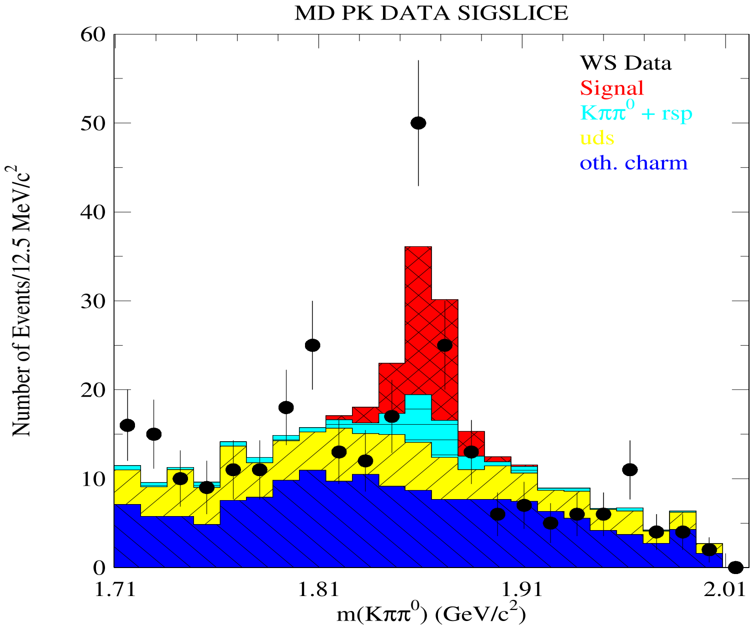
CLEO studied the rich resonant substructure (ρ^+, K^{*-}, $K^{*\circ}$, ...) of the $D^\circ \to K^-\pi^+\pi^\circ$ decay.

Wrong Sign decay $D^\circ \to K^+\pi^-\pi^\circ$ may have different substructure [Gronau and Rosen].

Exhaustive detection efficiency analysis over the Dalitz plot showed that
$\frac{\bar{\varepsilon}_{RS}}{\bar{\varepsilon}_{WS}} = 1.00 \pm 0.02$ (stat).

Unbinned Max. Likelihood fit of 2D Q vs M($K\pi\pi^\circ$) distribution.

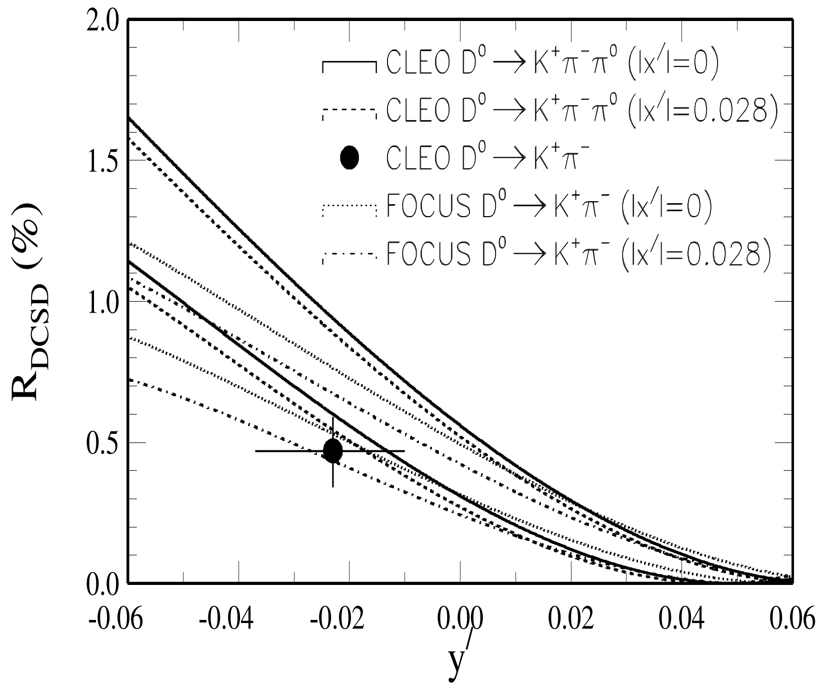




$$R_{WS} = 0.0043^{+0.0011}_{-0.0010} \text{ (stat)} \pm 0.0007 \text{ (syst)} \text{ (PRELIMINARY)}$$

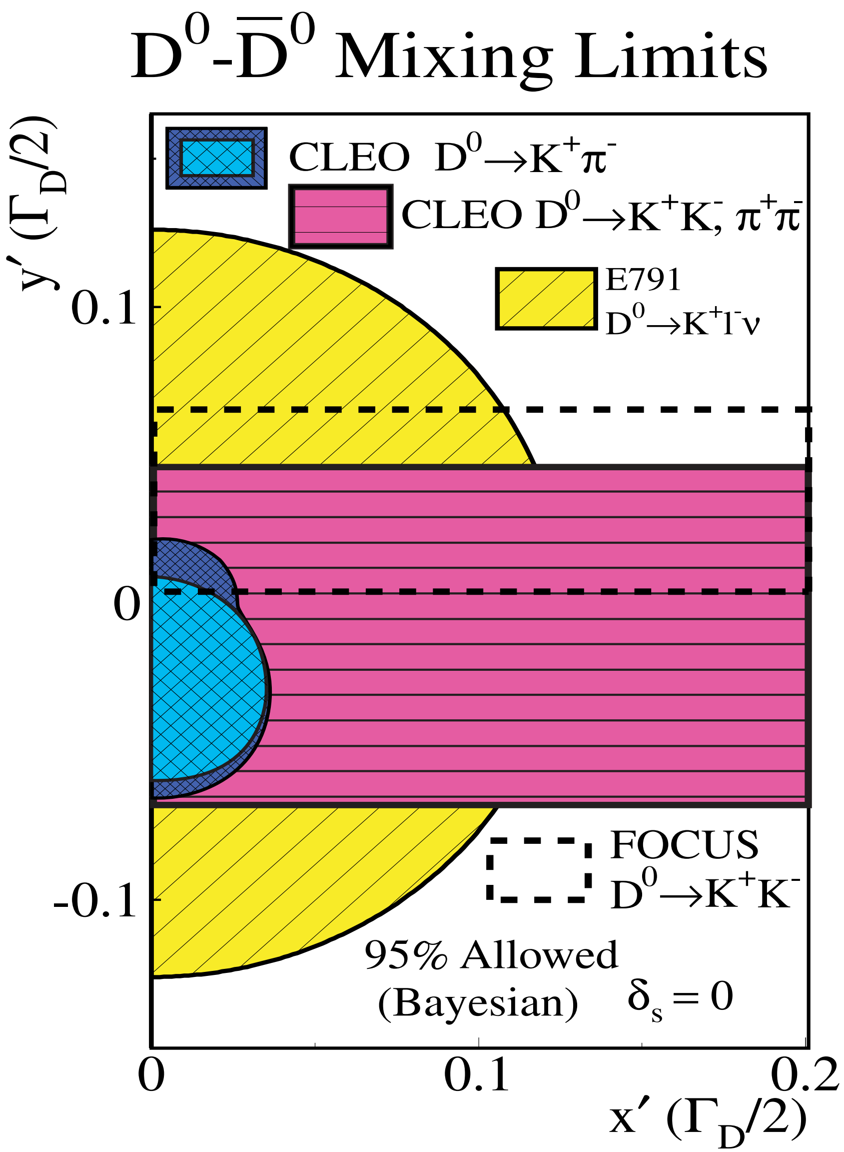
consistent with the CLEO II.V and FOCUS $D^0 \to K\pi$ measurements.

R_{WS} can be used to obtain limits on R_{DCSD} as a function of y' within limits on x' set by CLEO:



Notice, however, that x' and y' are different in $D^\circ \to K^-\pi^+$ and in $D^\circ \to K^-\pi^+\pi^\circ$

Summary of mixing measurements

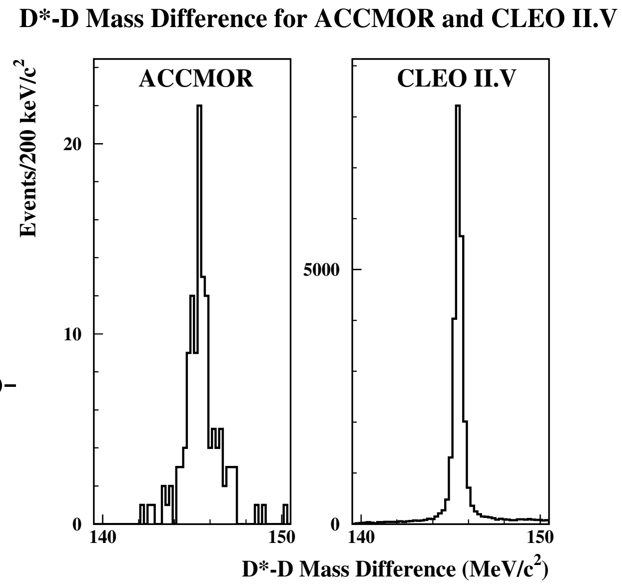


First measurement of $\Gamma(D^{*+})$

$\Gamma(D^{*+})$ **is dominated by strong decays** ($\mathcal{B}(D^{*+}\to D^+\gamma) = (1.68 \pm 0.45)\%$ is small)

Measurement of $\Gamma(D^{*+})$ opens important window on the non-perturbative strong physics involving heavy quarks. Predictions: $15 < \Gamma(D^{*+}) < 150$ keV.

Previous measurement:
$\Gamma(D^{*+}) < 131$ keV [ACCMOR(1992), 110 events]



CLEO II.V: 13,337 events: $D^{*+}\to\pi^+_{slow}D^0$, $D^0\to K^-\pi^+$

Challenge: understand and minimize tracking errors.
Take into account *tracking mishaps*.
Use and check Monte Carlo simulation of detector, in the absence of physical calibration.

FIT METHOD: Unbinned maximum Likelihood of
$\mathbf{Q} \equiv \mathbf{M}(\mathbf{K}^-\pi^+\pi^+_{\mathbf{slow}}) - \mathbf{M}(\mathbf{K}^-\pi^+) - \mathbf{M}(\pi^+)$, σ_Q

with Breit Wigner (P-wave Γ) convoluted with resolution Gaussian(s) (width σ_Q), small polynomial background.

Three kinds of selected samples:

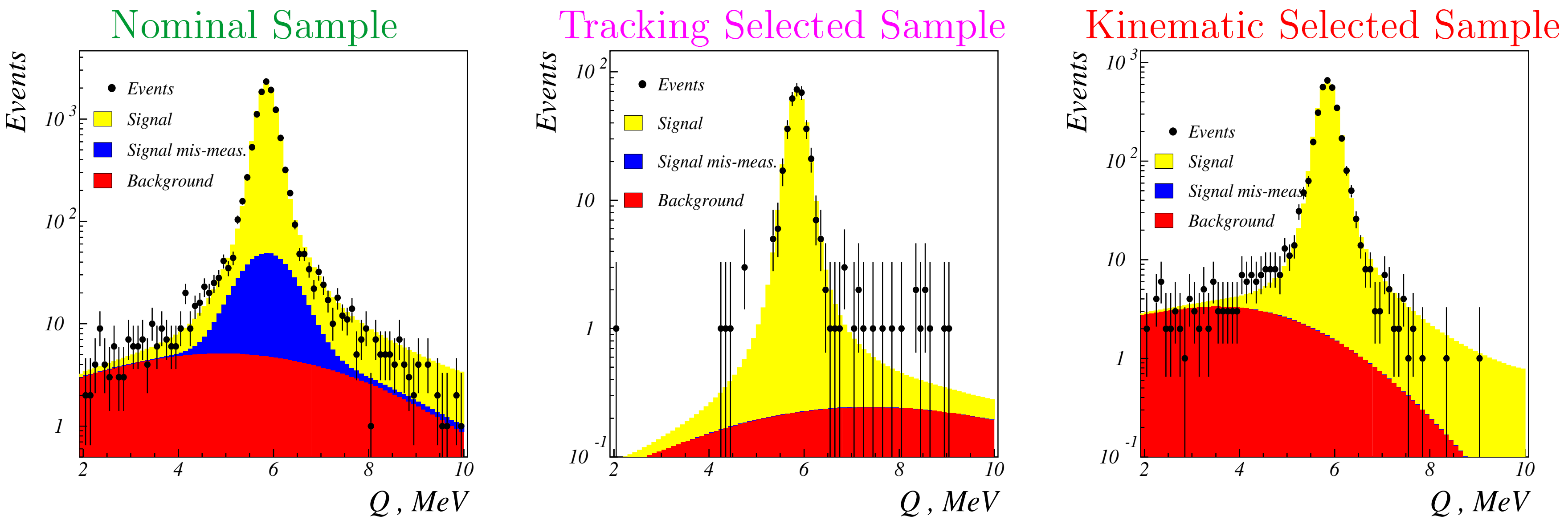
Raw Sample (13,337 events):

1. standard track selection;
2. vertex fitting;
3. exploit narrow beam ribbon.

Nominal Sample (11,496 events):
Additional cuts on $p(\pi_{slow})$ and D^{*+} decay opening angle θ vs $p(D^{*+})$, also $\sigma_Q < 200$ keV.

Kinematic Selected Sample (3,284 events): events with kinematical configuration that minimizes sensitivity on $p(\pi_{slow})$ and $p(D^\circ)$ errors.

Tracking Selected Sample (368 events): much stricter cuts on tracking parameters:



First measurement of $\Gamma(D^{*+})$: Result

The fitting procedures for all three types of samples were tested on large Monte Carlo full simulations generated with $0 < \Gamma(D^{*+}) < 130$ keV.

Offsets between the generated and measured values of Q in the three samples are consistent with zero but were used anyway.

Fits of the three samples are in excellent agreement:

Raw: $\Gamma(D^{*+}) = 99.9 \pm 3.6$ keV, Nominal: $\Gamma(D^{*+}) = 96.2 \pm 4.0$ keV,
Tracking: $\Gamma(D^{*+}) = 104 \pm 20$ keV, Kinematic: $\Gamma(D^{*+}) = 103.8 \pm 5.9$ keV.

Since the systematic errors essentially the same in the three samples, we choose as overall result the one from the Nominal Sample:

$$\boxed{\Gamma(D^{*+}) = 96 \pm 4 \pm 22 \text{ keV}}$$ PRELIMINARY

$\Lambda_c \overline{\Lambda}_c$ correlations in $e^+e^- \to c\overline{c}$

In $e^+e^- \to c\overline{c}$ at sufficiently high energy, one expects that the kind of charm hadron produced in the c jet be largely independent of what kind of anti-charm hadron is produced in the $\overline{c}$ jet.

When baryons are produced, we expect *and generally see* that baryon and anti-baryon are close in rapidity.

We found that is not true in Λ_c production.

We found: $$f_{\overline{\Lambda}_c^-}(c \to \Lambda_c^+) = 3.5 \times f_{\overline{D}}(c \to \Lambda_c^+)$$

No such correlation found in events that contained an additional proton.

Check: no correlation found for D vs $\overline{D}$, as expected.

Actually measured quantity is Ratio of Production Ratios:

$$\frac{\Lambda_c^+ | \overline{\Lambda}_c^-}{\overline{\Lambda}_c^-} \div \frac{\Lambda_c^+ | \overline{D^0}}{\overline{D^0}}$$

This ratio of ratios eliminates most of the systematic errors.

Three Λ_c decay modes were used: $pK^-\pi^+$, pK_s^0, $\Lambda\pi^+$, $\Lambda\pi^+\pi^-\pi^+$, $pK_s^0\pi^+\pi^-$, and $\Lambda + X$.

Only charm hadrons with $p > 2.3$ GeV considered.

Actual result:

$$\frac{\Lambda_c^+|\Lambda_c^-}{\Lambda_c^-} \div \frac{\Lambda_c^+|\overline{D^0}}{\overline{D^0}} = 3.5 \pm 0.6 \pm 0.4$$

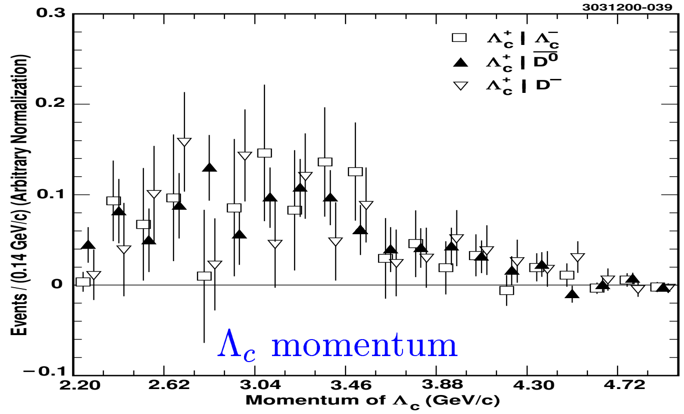
Systematic errors (that do not cancel in ratios):

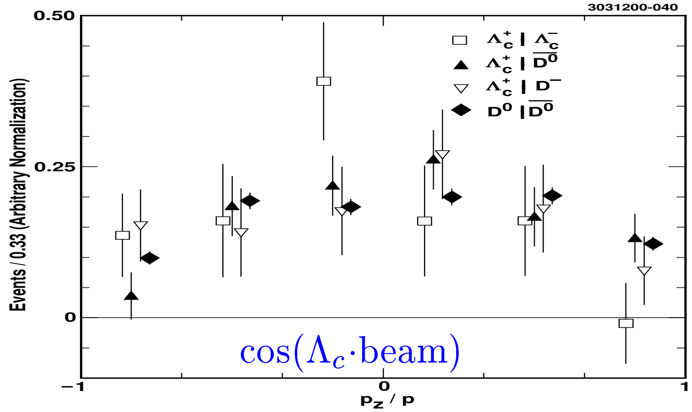
- 6% from signal shape parametrization, definition of "signal" and "side" bands. Results from 2D fits differed $< 5\%$.
- 7% from variation of minimum momentum cut.

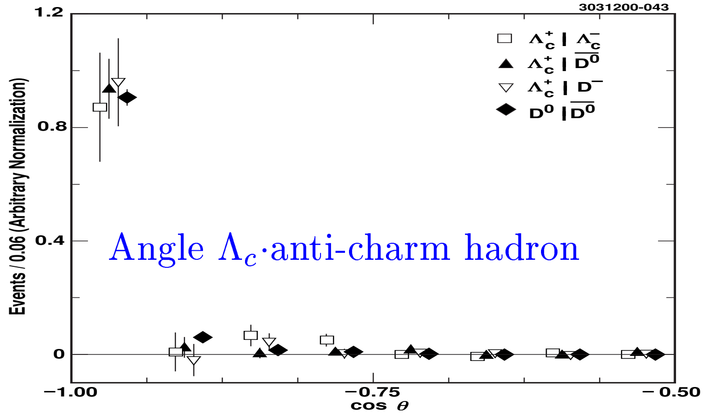
- Λ_c momentum and
- angular correlations with beam and
- angular correlations with the anti-charm hadron in $\bar{c}$ jet

are as expected for the jet's leading hadron and independent of the kind of anti-charm hadron in the $\bar{c}$ side of the event.

JETSET has no mechanism to generate this kind of correlation.







Omitted Topics

- A Search for Charmless $B \rightarrow VV$ Decays [hep-ex/0101029]
- Bounds on the CP Asymmetry in $b \rightarrow s\gamma$ Decays [hep-ex/0010075]
- Study of $B \rightarrow \psi(2S)K$ and $B \rightarrow \psi(2S)K^*(892)$ Decays, Phys.Rev. D63 (2001) 031103 [hep-ex/0010036]
- Study of χ_{c1} and χ_{c2} Meson Production in B Meson Decays: Phys.Rev. D63 (2001) 031102 [hep-ex/0009044]
- First Observation of the Decays $B^0 \rightarrow D^{*-} p\bar{p}\pi^+$ and $B^0 \rightarrow D^{*-} p\bar{n}$ [hep-ex/0009011]
- Dalitz Analysis of the Decay $D^0 \rightarrow K^-\pi^+\pi^0$ [hep-ex/0011065]
- Observation of the Ω_c^0 Charmed Baryon at CLEO [hep-ex/0010035]
- Evidence of New States Decaying into $\Xi_c'\pi$ [hep-ex/0012020]
- Search for Direct CP Violation in Ξ Hyperon Decay [hep-ex/0009037]
- A Measurement of the Decay Asymmetry Parameters in $\Xi_c^0 \rightarrow \Xi^-\pi^+$ [hep-ex/0011073]
- Measurement of the Λ_c^+ Lifetime [hep-ex/0011049]
- Observation of New States Decaying into $\Lambda_c^+\pi^-\pi^+$ [hep-ex/0010080]
- Study of τ Decays to Six Pions and Neutrino [hep-ex/0010025]