CLEO

CLEO I.5

CLEO II

CLEO II.V

CLEO III

Recent Results on Beauty and Charm

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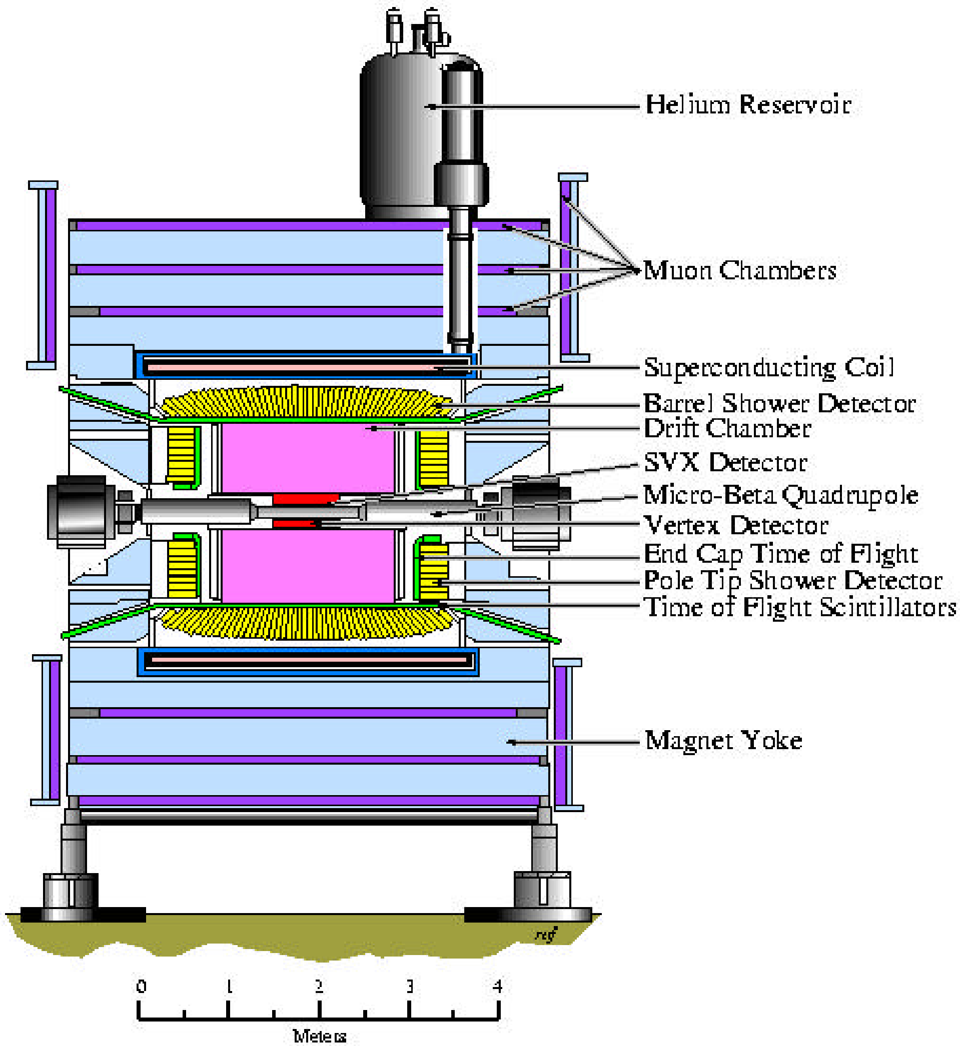
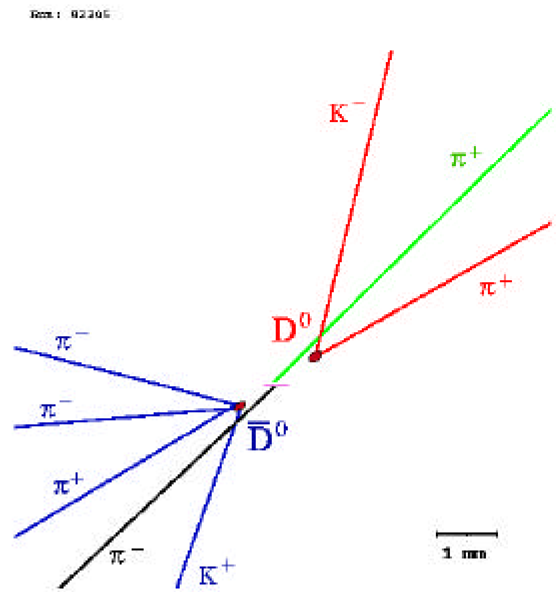
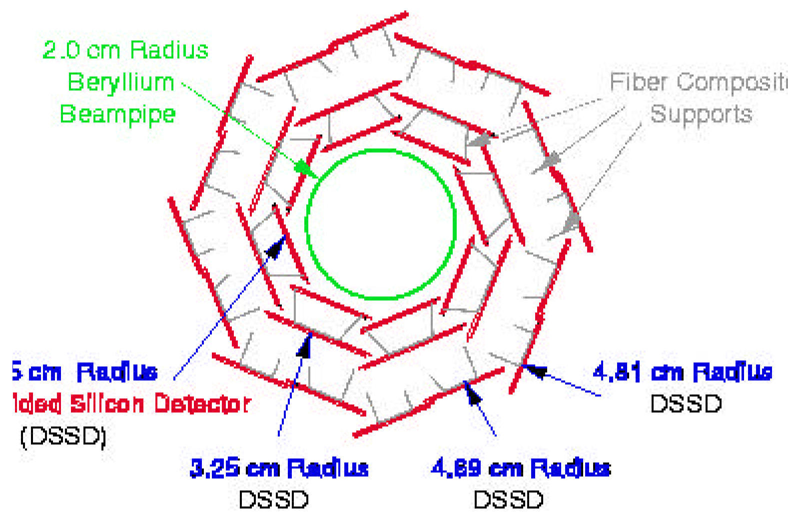
SLAC Summer Institute 2000

CLEO II (90 – 95) and CLEO II.V (95-99)







CLEO Data Set

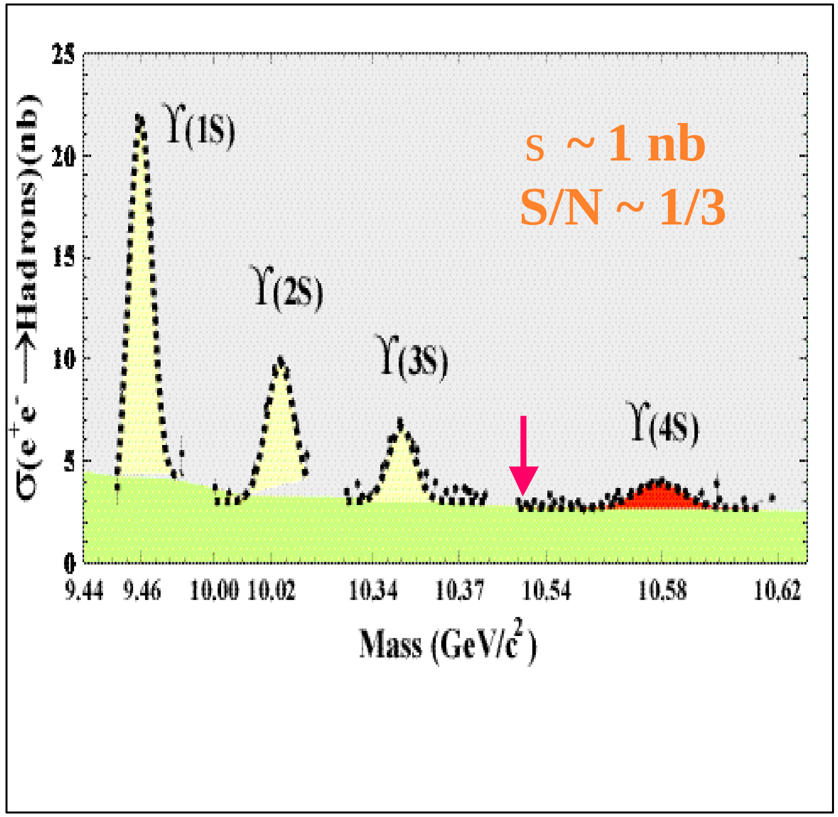
- CESR - symmetric e^+e^- storage ring
  - operates on Υ(4S)
- BB produced near threshold

$$\sigma(B\bar{B}) = 1.05 \text{ nb}$$
$$p_B \approx 300 \text{ MeV/c}$$

- "Continuum" production

$$\sigma(cc) = 1.3 \text{ nb}$$
$$\sigma(qq) = 2.1 \text{ nb}$$

- Data set
  - CLEO II - 1/3 of the data
  - CLEO II.V - 2/3 of the data
  - Totals
    - ~ 9.1 fb^{-1} on Υ(4S)
    - ~ 4.4 fb^{-1} off Υ(4S)



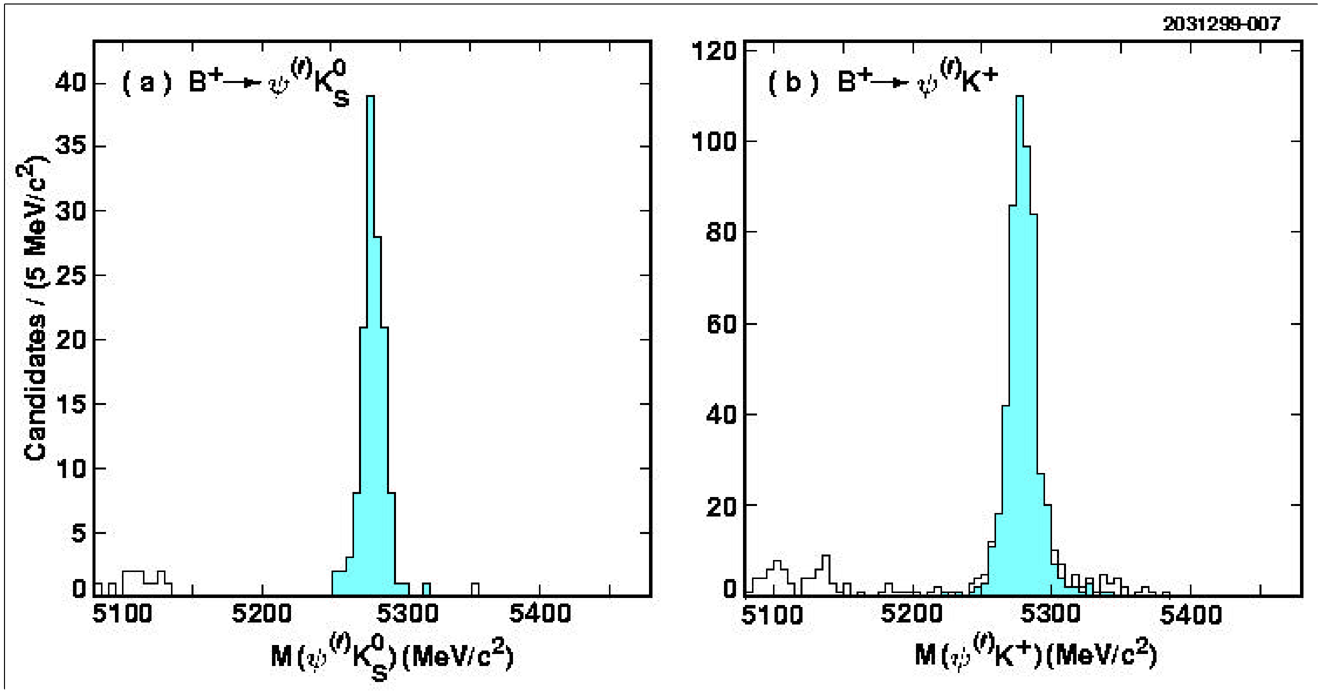
B Meson Mass

- Use fully reconstructed (hadronic) B decays

- Previous CLEO measurements
  - fit beam constrained mass for B-> D(*)nπ and ψK(*)
    $M_{bc}^2 = E^2_{beam} - p^2$ and $\sigma(M_{bc}) \sim \sigma(E_{beam}) \sim 2.7$ MeV
  - Systematic limited:
    - error on beam energy scale ~ 2 MeV
    - error on initial state radiation correction ~0.5 MeV

- New result
  - exclusively reconstruct B-> $\psi^{(\prime)}$K
  - do not use beam energy constraint
  - constrain $\psi^{(\prime)}$ to PDG values

B Meson Mass (2)



$m(B^0)$ [MeV] = 5279.1 +/- 0.7 +/- 0.3 (5279.2 +/- 1.8 PDG98)

$m(B^+)$ [MeV] = 5279.1 +/- 0.4 +/- 0.4 (5278.9 +/- 1.8 PDG98)

(for reference: Δm_B = 0.34+/- 0.32)

B Meson Production at the Y(4S)

Define $$\frac{f_{oo}}{f_{+-}} = \frac{?\,(Y(4S) \rightarrow B^{o}\overline{B}^{o})}{?\,(Y(4S) \rightarrow B^{-}B^{+})}$$

Any comparison of B^+ and B^0 rates depends on f_{+-}/f_{00}

PDG assumes $f_{+-}/f_{00} = 1$

Theoretical predictions: 0.95 ~ 1.05

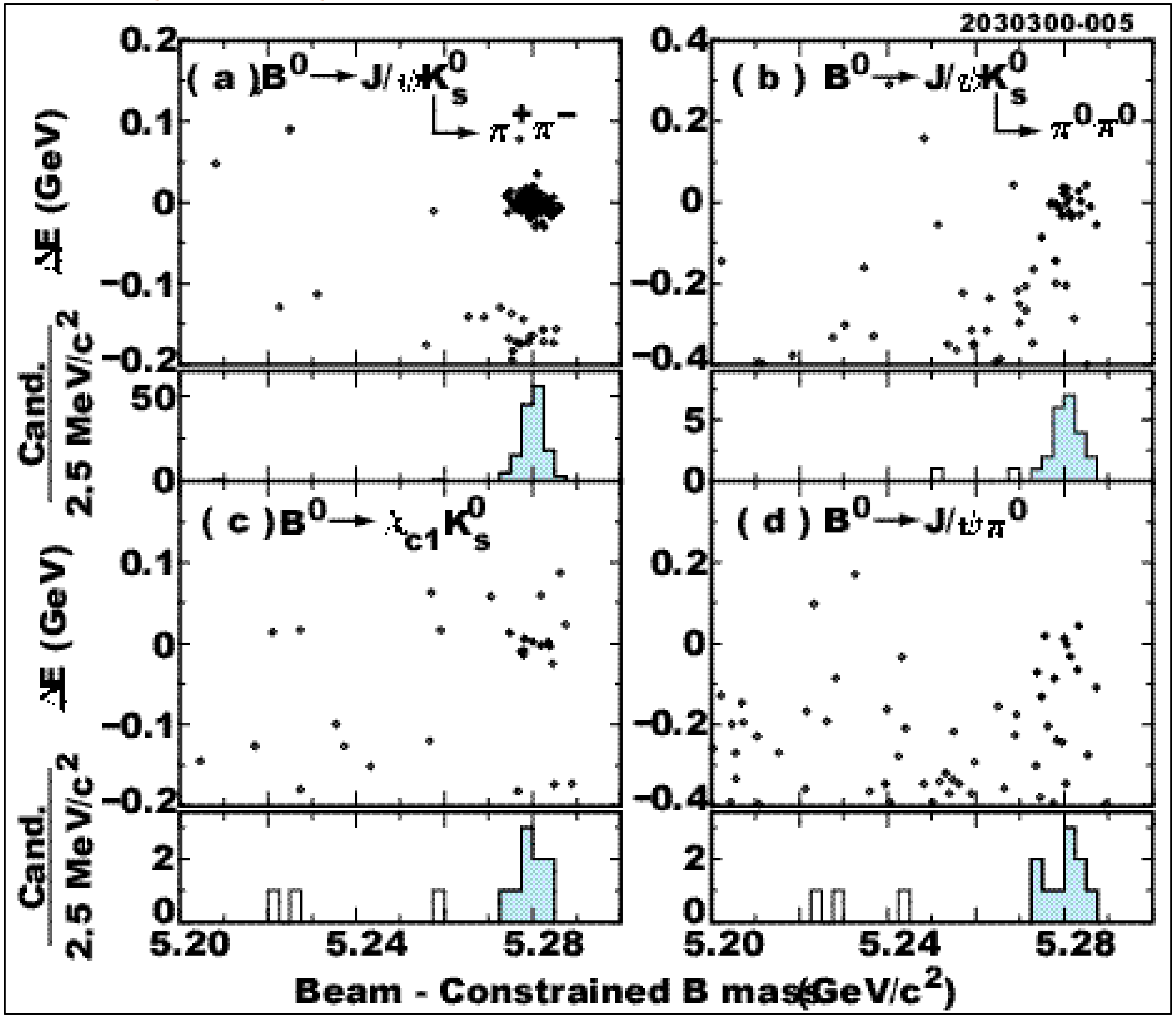
Assuming Isospin conservation:

$$\Gamma(B^+ \text{-> } \psi K^{(*)+}) = \Gamma(B^0 \text{-> } \psi K^{(*)0})$$

we find

$$f_{+-}/f_{00} = 1.04 \text{ +/- } 0.07 \text{ +/-} 0.04$$

More results on B to Charmonium



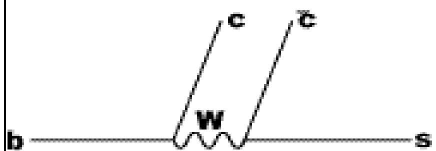
B to Charmonium branching fractions

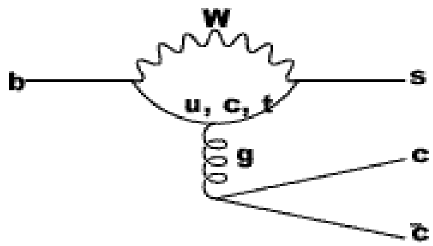
	Decay Mode	Signal	Background	BR ($\times 10^{-4}$)
	B^0 -> y K^0			9.5+/-0.8+/-0.6
Update	K_s -> p^+p^-	142	0.3+/-0.2	9.8+/-0.8+/-0.7
New	K_s -> p^0p^0	22	1.1+/-0.3	8.4+/-2.0+/-0.7
New	B^0 -> $c_{c1}K^0$	9	0.9+/-0.3	$3.9^{+1.9}_{-1.3}$+/-0.4
New	B^0 -> y p^0	10	1.0+/-0.5	0.25+/-0.10+/-0.02
New	B -> y f K	10	0.5+/-0.2	$0.88^{+0.35}_{-0.30}$+/-0.13
New	B^+ -> h_cK^+			$6.9^{+2.6}_{-2.1}$+/-2.1
New	B^0 -> h_cK^0			$10.9^{+5.5}_{-4.2}$+/-3.3

Search for Direct CP Violation

$$\mathcal{A}_{CP} = \frac{\mathcal{B}(B^- \to \psi^{(\prime)} K^-) - \mathcal{B}(B^+ \to \psi^{(\prime)} K^+)}{\mathcal{B}(B^- \to \psi^{(\prime)} K^-) + \mathcal{B}(B^+ \to \psi^{(\prime)} K^+)} = \frac{b - \bar{b}}{b + \bar{b}}$$

- We can measure $\mathcal{A}_{CP}(\psi K^\pm)$ with 4% precision
- In Standard Model $\mathcal{A}_{CP}(\psi K^\pm) << 4\%$ (even if penguin amplitude is large)
- $\mathcal{A}_{CP} = \frac{-2A_1 A_2 \sin(\delta_1 - \delta_2)_{strong} \sin(\phi_1 - \phi_2)_{weak}}{A_1^2 + A_2^2 + 2A_1 A_2 \cos(\delta_1 - \delta_2)\cos(\phi_1 - \phi_2)}$





- $A(c\bar{c}s) = V_{cb}V_{cs}^*(T_{c\bar{c}s} + P_c - P_t) + V_{ub}V_{us}^*(P_u - P_t)$
- $\arg(V_{ub}V_{us}^*/V_{tb}V_{ts}^*) \simeq \lambda^2\eta + \pi$ $(\lambda = 0.22,\ \eta \lesssim 1)$

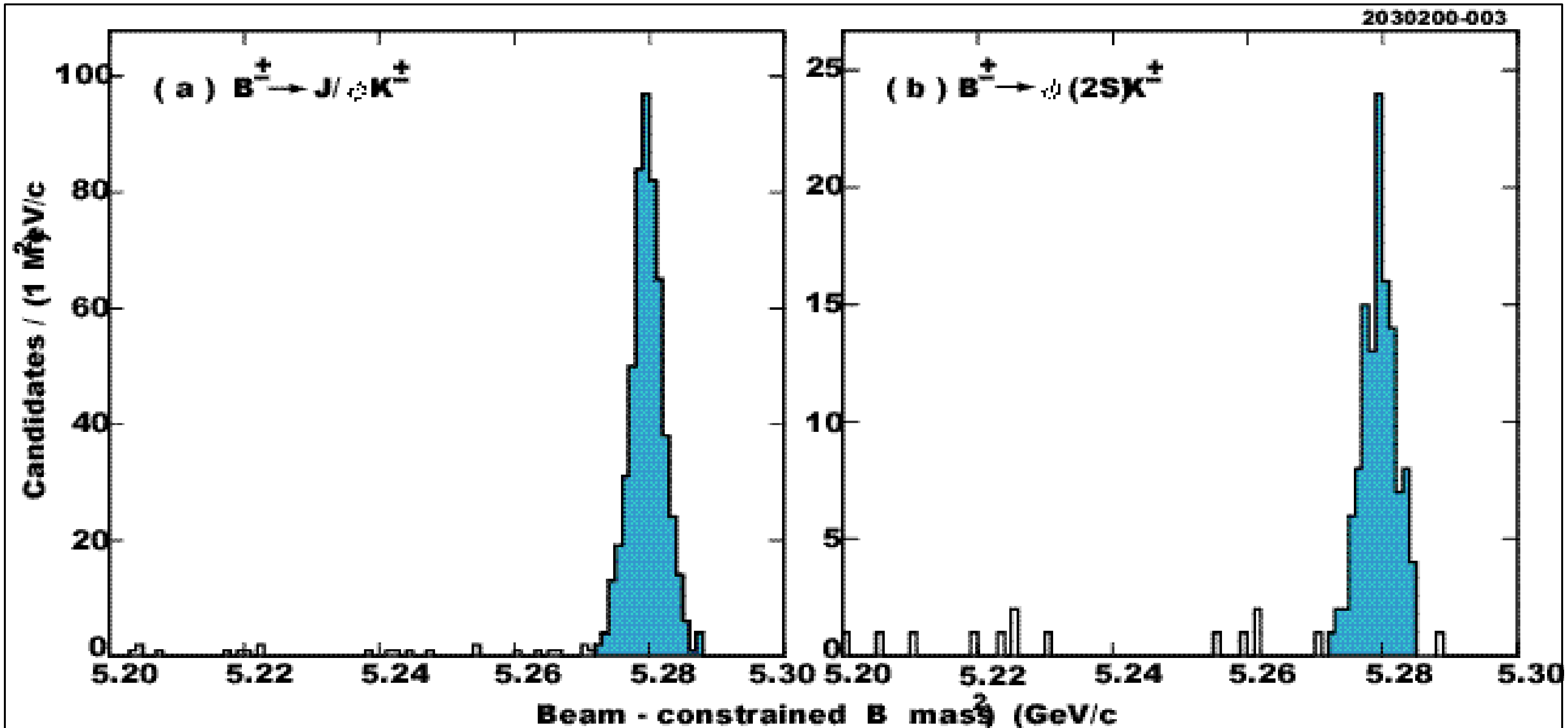
<u>One of the models beyond the Standard</u>

Two-Higgs doublet model with special status for top quark

(Kiers, Soni, and Wu, hep-ph/9911419)

- H^--mediated diagram competes with SM tree W^--mediated diagram and comes with its own CP-odd phase
- $\mathcal{A}_{CP}(\psi K^\pm)$ could be $\mathcal{O}(10\%)$ $\Longrightarrow$ we can measure it right now

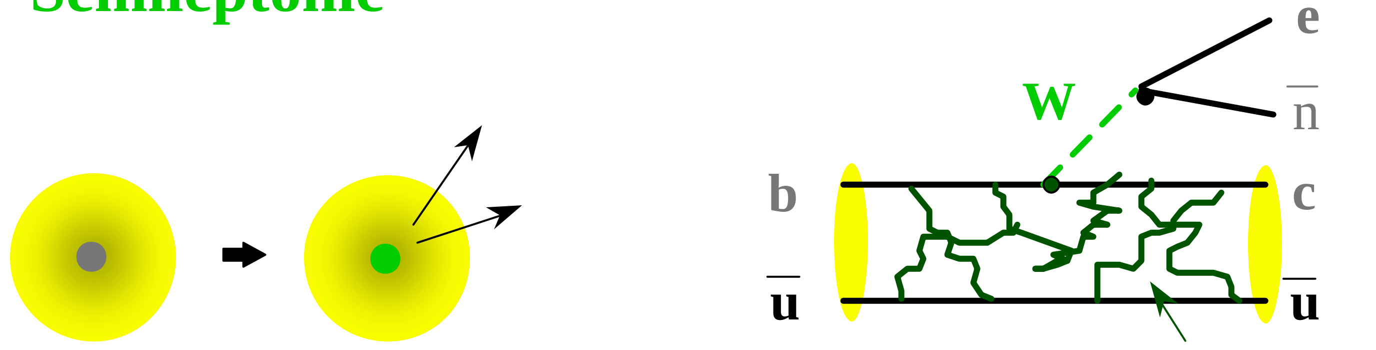
Search for Direct CP Violation



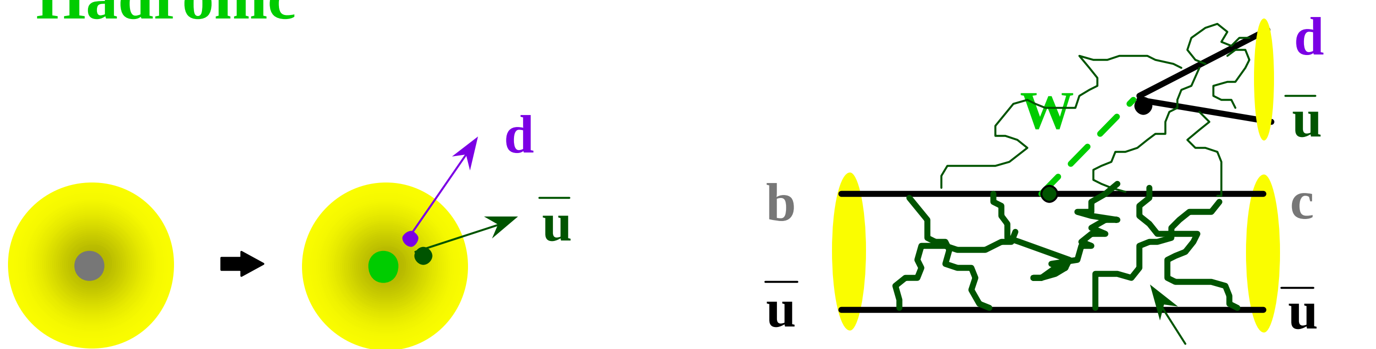
Mode	$N(B^\pm)$	$N(B^-)$	$N(B^+)$	$\frac{N(B^-)-N(B^+)}{N(B^-)+N(B^+)}$	$\mathcal{A}_{CP}$
$B^\pm \to J/\psi K^\pm$	534	271	263	$(+1.5 \pm 4.3)\%$	$(+1.8 \pm 4.3 \pm 0.4)\%$
$B^\pm \to \psi(2S) K^\pm$	120	61	59	$(+1.7 \pm 9.1)\%$	$(+2.0 \pm 9.1 \pm 1.0)\%$

Understanding Hadronic Decays

Semileptonic



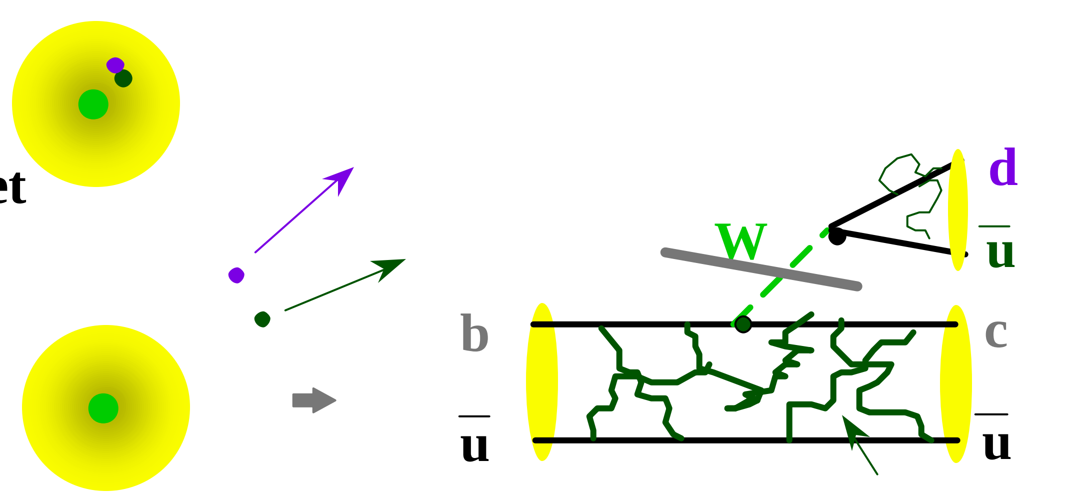
Hadronic



But if ...

W creates $\bar{u}$d pointlike
➡ color singlet

if they get out fast enough ...



Hadronic B Decays

- Semileptonic Decay

$$A = \frac{G_F}{\sqrt{2}} V_{cb} V_{ub}^{*} < n \,|\, g_m (1 - g_5) \,|\, l >< D^{*-} \,|\, (cb) \,|\, B^0 >$$

- Hadronic + Factorization

$$A = \frac{G_F}{\sqrt{2}} V_{cb} V_{ub}^{*} < p \,|\, (du) \,|\, 0 >< D^{*-} \,|\, (cb) \,|\, B^0 >$$

Factorization Tests:

- Branching Ratios

$$\frac{G(B \text{ ® } D^{*+} h^{-})}{\frac{dG}{dq^2}(B \text{ ® } D^{*+} l n)|_{q^2 = m_h^2}} = 6 p^2 c_1^{\,2} f_h^{\,2} |V_{ud}|^2$$

- Polarization

$$\Gamma_L/\Gamma\ (B \rightarrow D^{*+} h^-) \quad = \quad \Gamma_L/\Gamma\ (B \rightarrow D^{*+} l^- n)|_{q^2 = m_h^2}$$

Hadronic Decays and Factorization

(1997)

Semileptonic (e.g. B->D*-l+ ν)

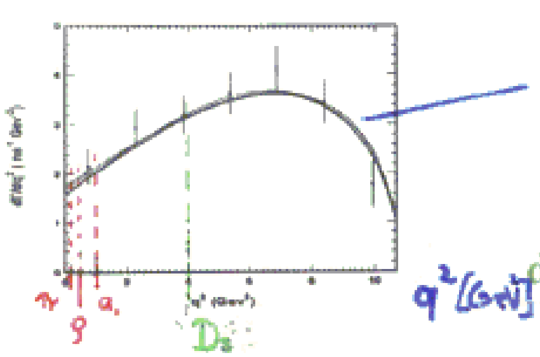
$$A = G_F/1.4\, V_{cb} \langle \nu|\gamma_\mu(1-\gamma_5)|l\rangle \langle D^{*-}|(cb)|B^0\rangle$$

Hadronic (+Factorization) (e.g. B->D*-š+)

$$A = G_F/1.4 V_{cb} \langle \pi|(du)|0\rangle \langle D^{*-}|(cb)|B^0\rangle$$

I. Branching Ratio Tests

Input: π decay constant ✓
semileptonic decay rate ✓



$$\frac{\Gamma(B^0 \to D^{*-} \pi^+)}{d\Gamma/dq^2(B^0 \to D^{*-} l^+ \nu)} = 6\pi^2 c_1^2 f_\pi^2 |V_{ud}|^2$$

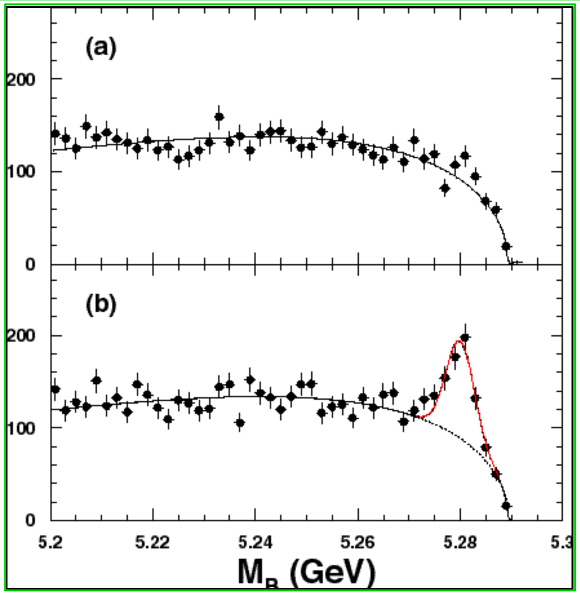
	B->D*	B->D	"Theory"
$B^0 \to D^{(*)-}\pi^+$	1.18+/-0.21	0.94+/-0.30	1.22+/-0.15
$B^0 \to D^{(*)-}\rho^+$	2.92+/-0.70	2.63+/-0.88	3.26+/-0.42
$B^0 \to D^{(*)-}a_1^+$	3.8+/-1.0		3.0+/-0.5

II. Polarization Tests

$\Gamma_L / \Gamma(B^0 \to D^{*-}\rho^+) = 90 \pm 7 \pm 5\%$ ⇒ $\Gamma_L / \Gamma(B^0 \to D^{*-} l^+ \nu) = 88\%$

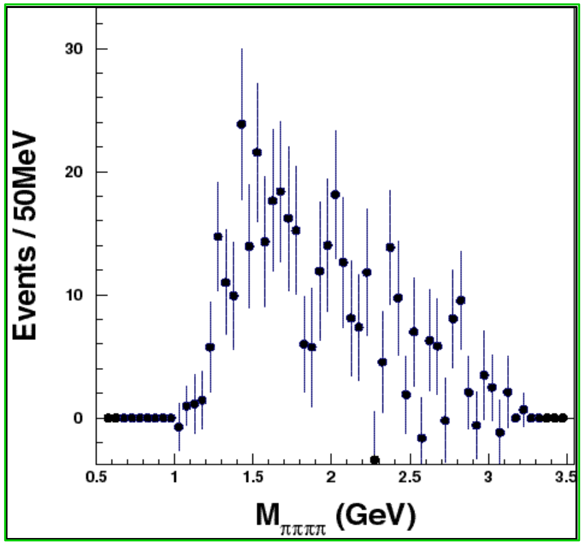
The $D^{*+}\pi^+\pi^-\pi^-\pi^o$ Final State

- (a) ΔE sidebands
  $|3.0 – 5.0\ \sigma|$
- (b) ΔE around 0 $\pm 2.0\sigma$ fit with sideband shape fixed & norm allowed to float
- Also signals in $D^o \rightarrow K^-\pi^+\pi^o$ and $D^o \rightarrow K^-\pi^+\pi^+\pi^-$ (not shown)
- Fit B yield in bins of $M(4\pi)$



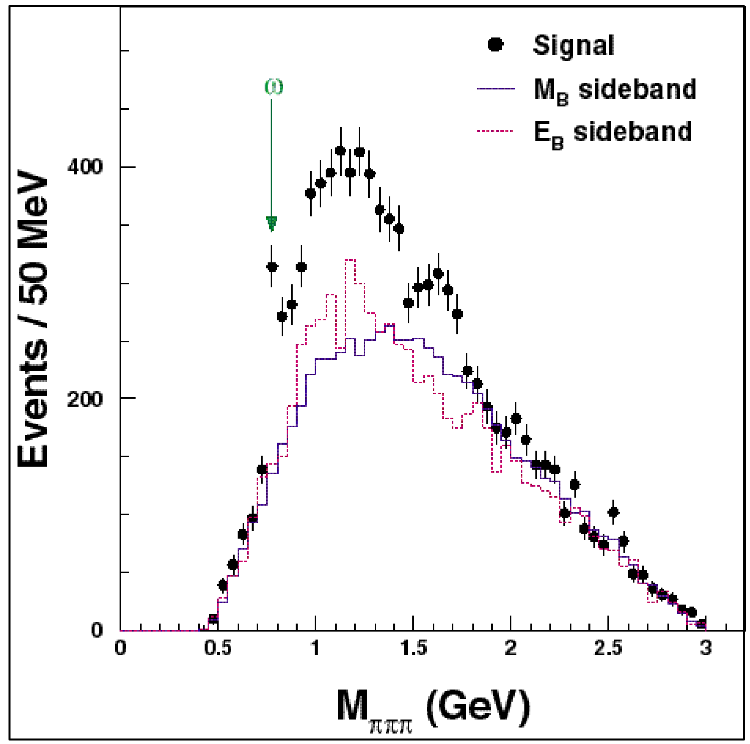
$(D^o \rightarrow K^-\pi^+)$

358±29

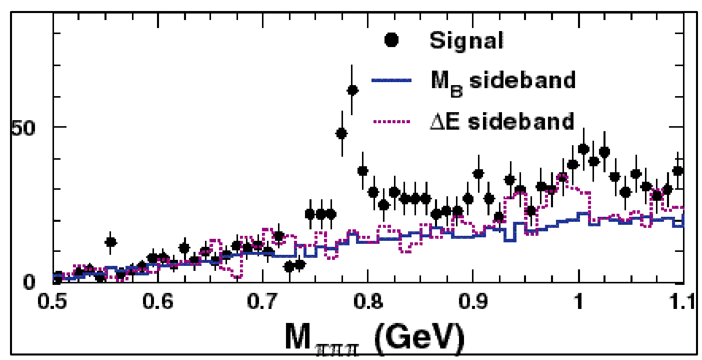


The $\pi^+\pi^- \pi^o$ Mass Distribution

- What are the decay mechanisms for the $(4\pi)^-$ final state?
- We examine the $\pi^+\pi^-\pi^o$ mass spectrum (2 combinations/event). All 3 D^o decay modes summed



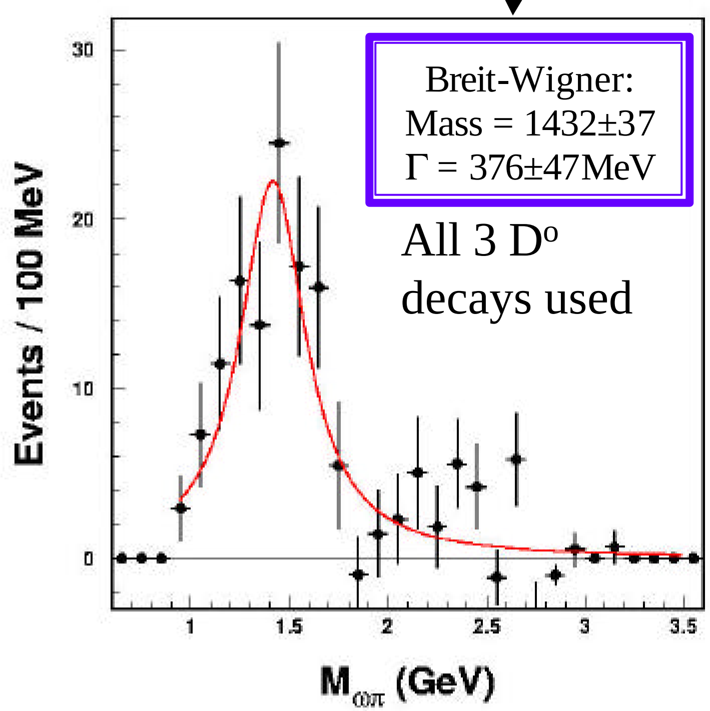
Enlarged & Dalitz plot exterior removed



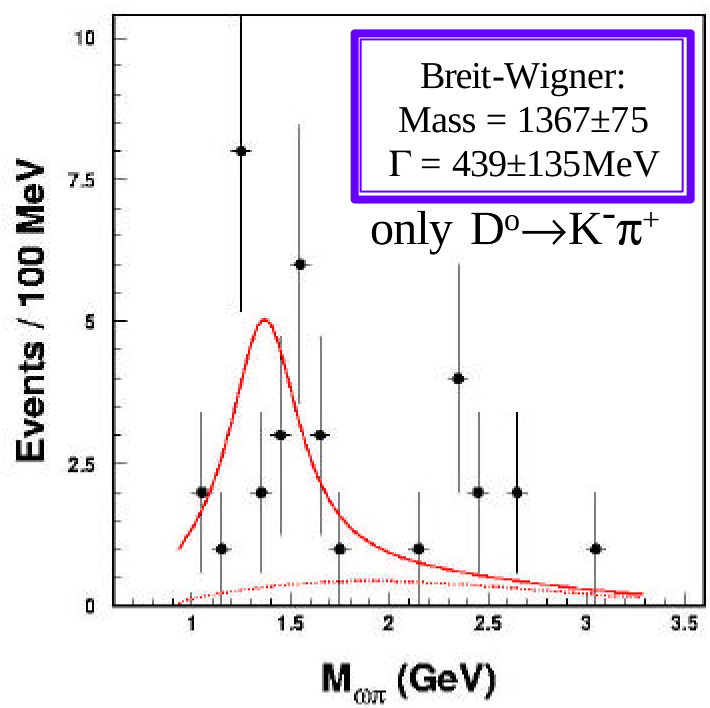
The $\omega\pi^-$ Mass Distribution

Fit M_B distribution in $\omega\pi$ mass bins

$D^{*+}\omega\pi^-$



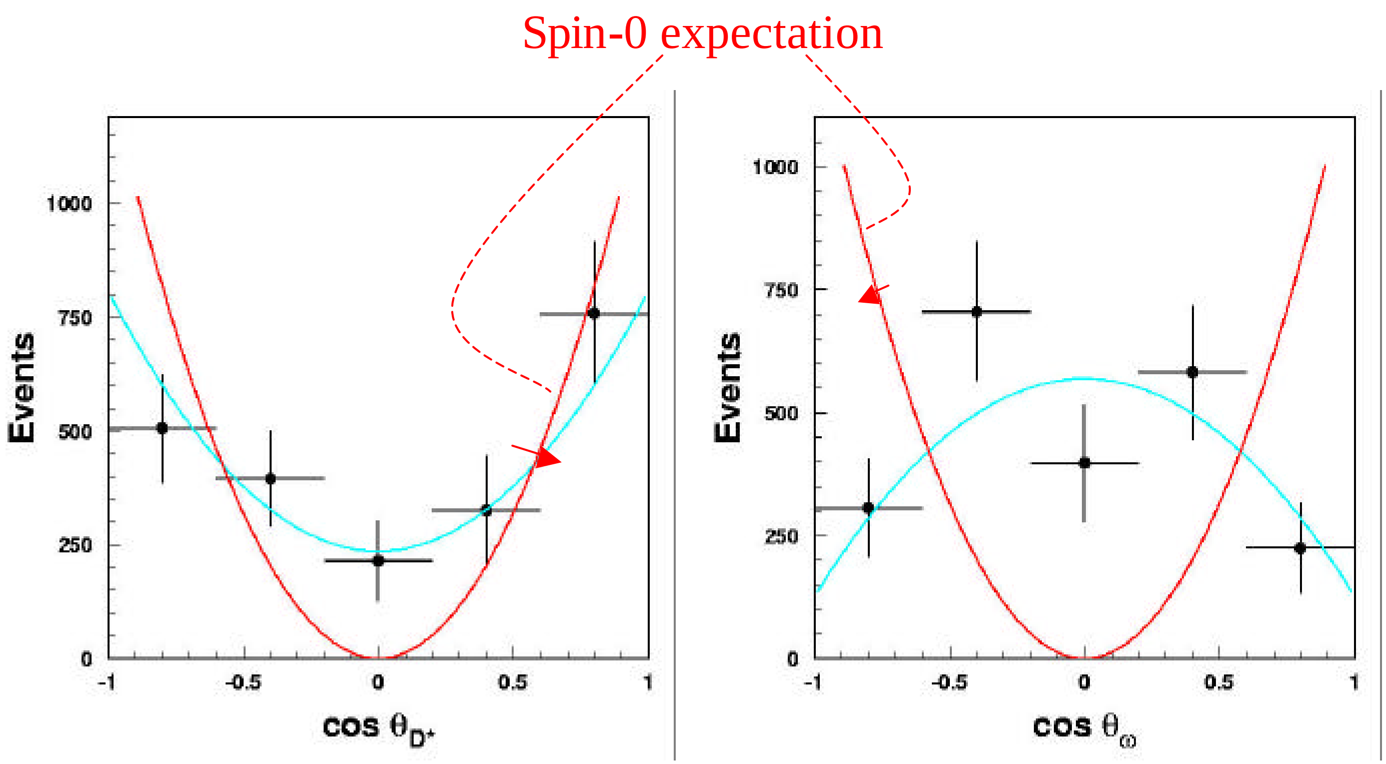
$D^{*o}\omega\pi^-$



Possible resonance (A) at M=1419±33 MeV, Γ=382±44 MeV

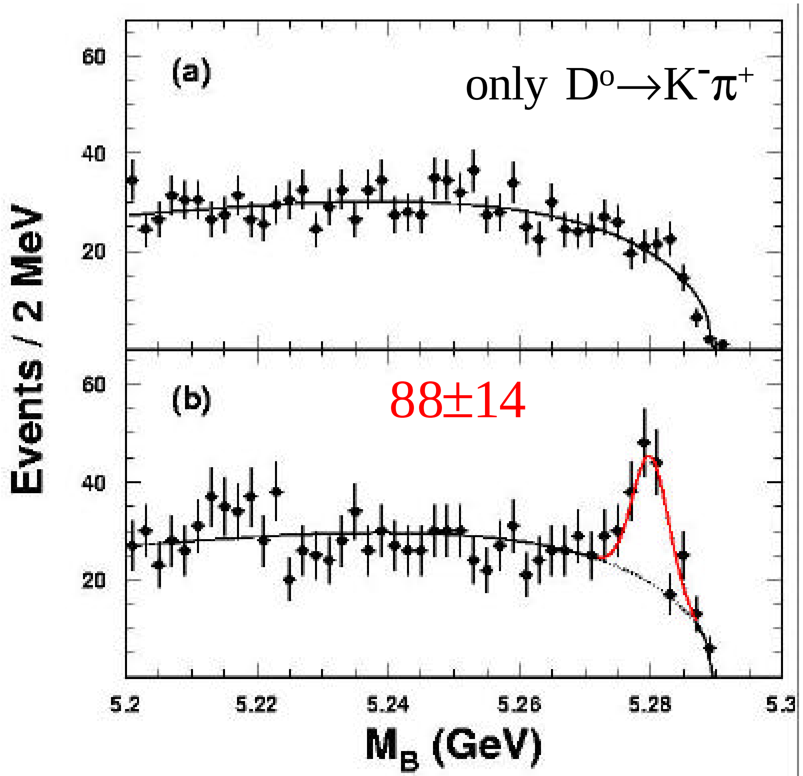
$D^{*+}(\omega\pi)^-$ Angular Distributions

- For a spin-0 A the D* & ω would be fully polarized
- Spin 0 ⇒ χ^2/dof = 3.5 ($\cos\theta_{D*}$), 22 ($\cos\theta_\omega$) ⇒ Ruled out
- Best fit ⇒ Γ_L/Γ = 0.63±0.09 (D^{*+}), 0.10±0.09 (ω)

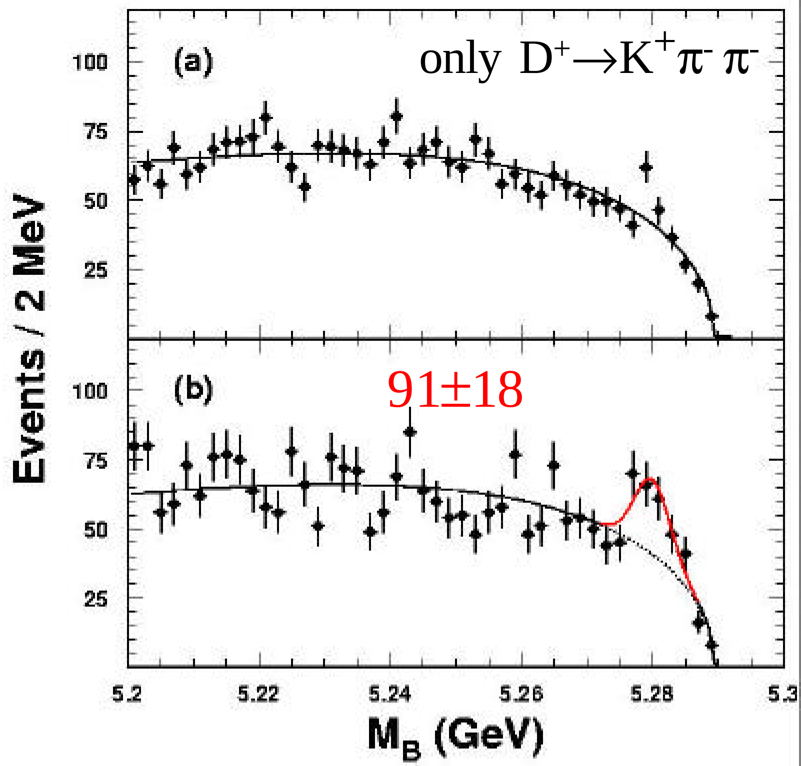


The $D\omega\pi^-$ Final State

$D^\circ\omega\pi^-$

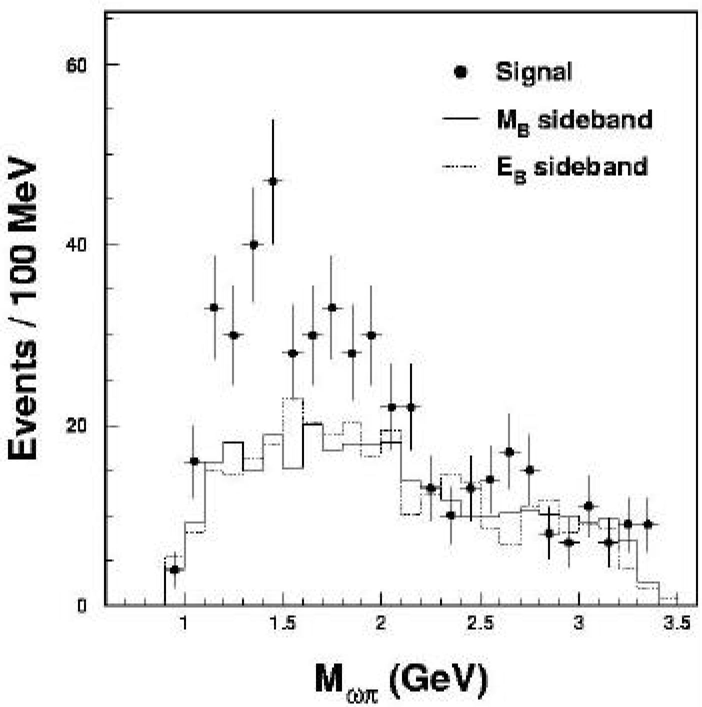


$D^+\omega\pi^-$

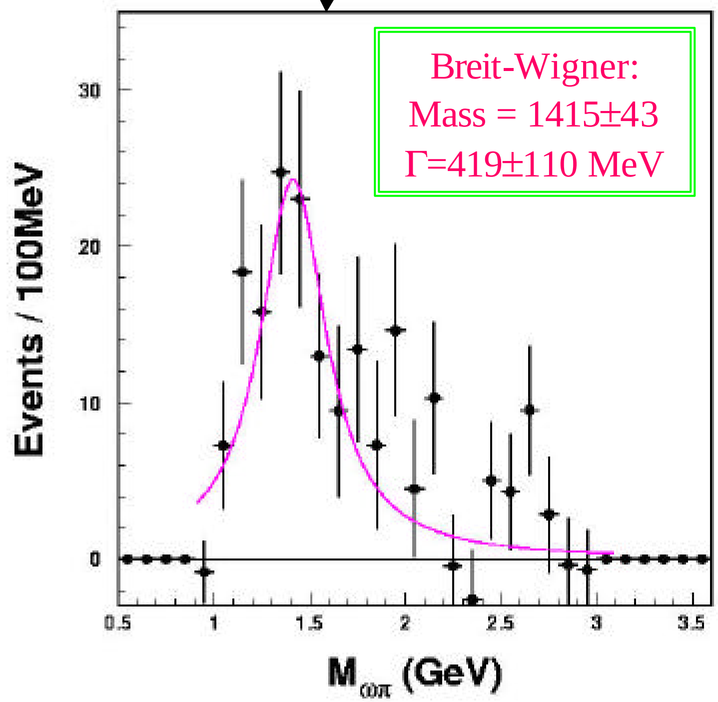


- Signal: $|\Delta E|<2\sigma$ (18MeV) Sideband: $3\sigma<|\Delta E|<7\sigma$
- No signal in ω sidebands

The $\omega\pi^-$ Mass Distribution



Fit M_B distribution in $\omega\pi$ mass bins



- Combined $D^\circ\omega\pi^-$ and $D^+\omega\pi^-$ modes (179 events)
- Consistent with $D^*\omega\pi$ result
- Select (1.1–1.7 GeV) for angular study (104 events)

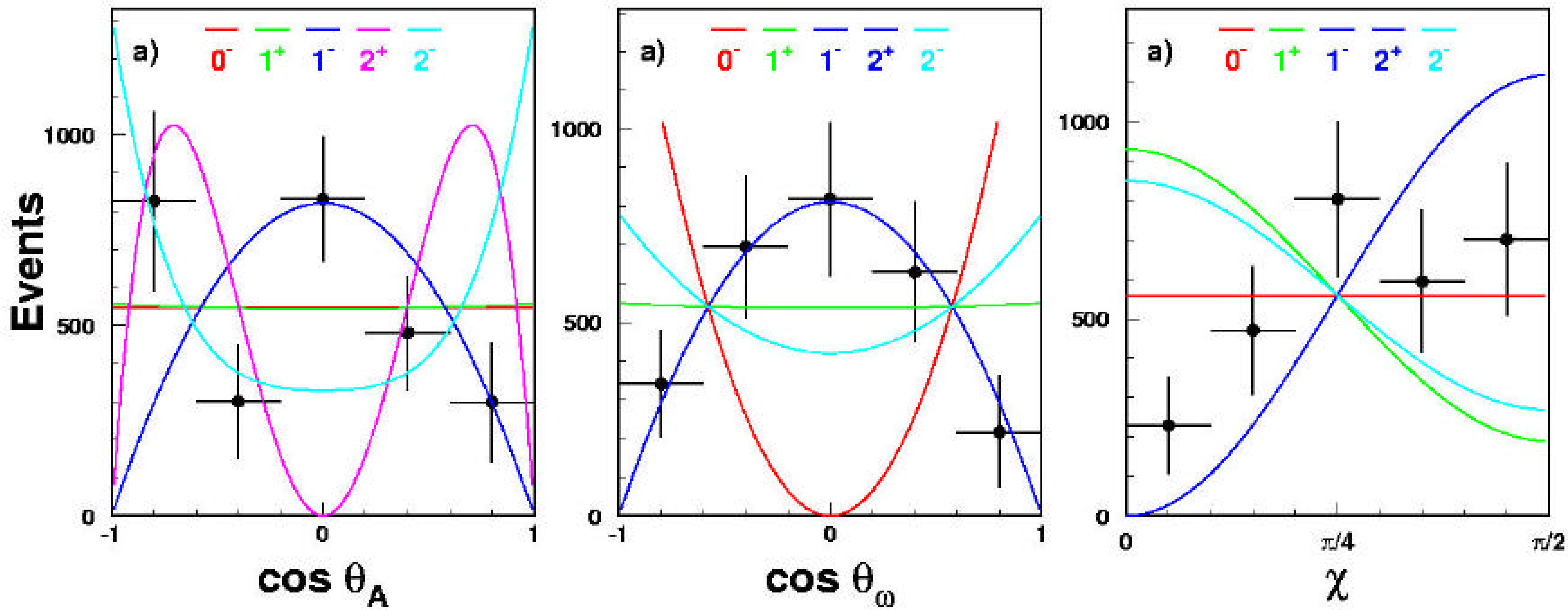
The Angular Distributions in

B → D A⁻: A⁻ → ω π⁻, ω → π°π⁺π⁻

∠ between ω in A frame & A boost direction

∠ between normal of ω decay plane & ω boost

∠ between A & ω decay planes



- Small efficiency corrections applied
- For 1^+ and 2^-, the longitudinal ratio (Γ_L/Γ) floats
- 1^- preferred, χ^2/dof (1^-) = 1.7, (2^+) = 3.2
- A^- properties: mass = 1418±26±19 MeV, Γ=388±41±32 MeV

Identifying the A^- with the ρ'

- Clegg & Donnachie: ($\tau\to(4\pi)\nu$, $e^+e^-\to\pi^+\pi^-$, $\pi^+\pi^+\pi^-\pi^-$) find two 1^- states with (M, Γ)= (1463±25, 311±62) MeV & (1730±30, 400±100) MeV, mixed with non-qq states, only the lighter one decays to $\omega\pi$
- Godfrey & Isgur: Predict first radial excited ρ at 1450 MeV, Γ=320 MeV, $B(\rho'^-\to\omega\pi^-)$=39%

Summary & Discussion of Rates

Mode	Br (%)	# of events
$\overline{B}^\circ \to D^{*+}\pi^\circ\pi^+\pi^-\pi^-$	1.72±0.14±0.24	1230±70
$\overline{B}^\circ \to D^{*+}\omega\pi^-$	0.29±0.03±0.04	136±15
$\overline{B}^\circ \to D^{+}\omega\pi^-$	0.28±0.05±0.03	91±18
$B^- \to D^{*\circ}\pi^\circ\pi^+\pi^-\pi^-$	1.80±0.24±0.25	195±26
$B^- \to D^{*\circ}\omega\pi^-$	0.45±0.10±0.07	26± 6
$B^- \to D^{\circ}\omega\pi^-$	0.41±0.07±0.04	88±14

- ρ' dominates the $\omega\pi^-$ final state
- $\Gamma(\overline{B}^\circ \to D^{*+}\rho'^-)$ / $\Gamma(B^\circ \to D^+\rho'^-)$ = 1.04±0.21±0.06

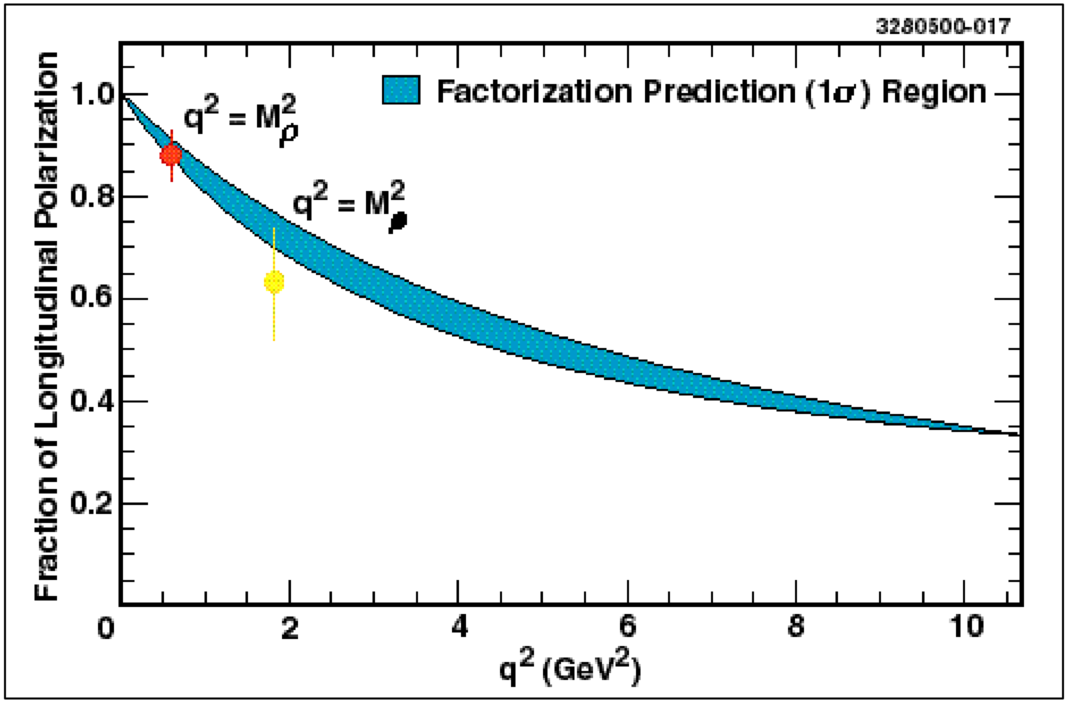
  $\Gamma(B^- \to D^{*\circ}\rho'^-)$ / $\Gamma(B^- \to D^\circ\rho'^-)$ = 1.10±0.31±0.06

  $\Gamma(B \to D^*\rho'^-)$ / $\Gamma(B \to D\rho'^-)$ = 1.06±0.17±0.04
- Consistent with Heavy Quark Symmetry prediction (ratio = 1)
- With $B(\rho'^- \to \omega\pi^-)$=39%, $\Gamma(B \to D^{(*)}\rho'^-) \sim \Gamma(B \to D^{(*)}\rho^-)$

Testing Factorization

Polarization:

$\Gamma_L/\Gamma\,(B\to D^{*+}h^-) = \Gamma_L/\Gamma\,(B\to D^{*+}l^-n)|_{q^2=m_h^2}$

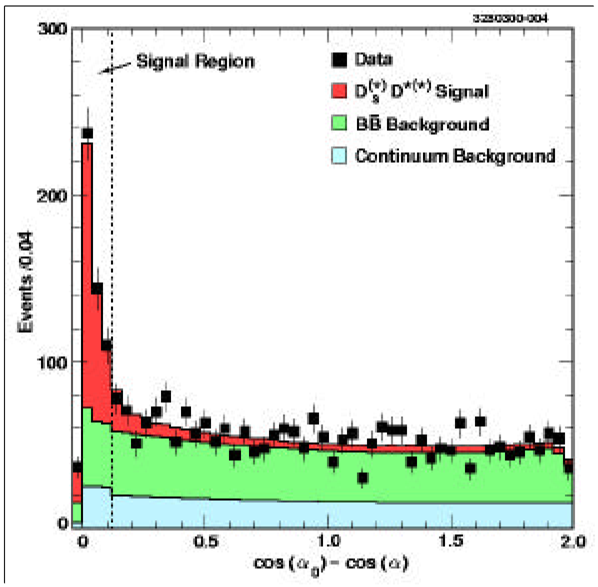


Branching Fractions:

$$\Gamma(B\to D^{*+}h^-)\,/\,d\Gamma/dq^2\,(B\to D^{*+}l^-n)|_{q^2=m_h^2} = 6\pi^2 c_1^2 f_h^2\,|V_{ud}|^2$$

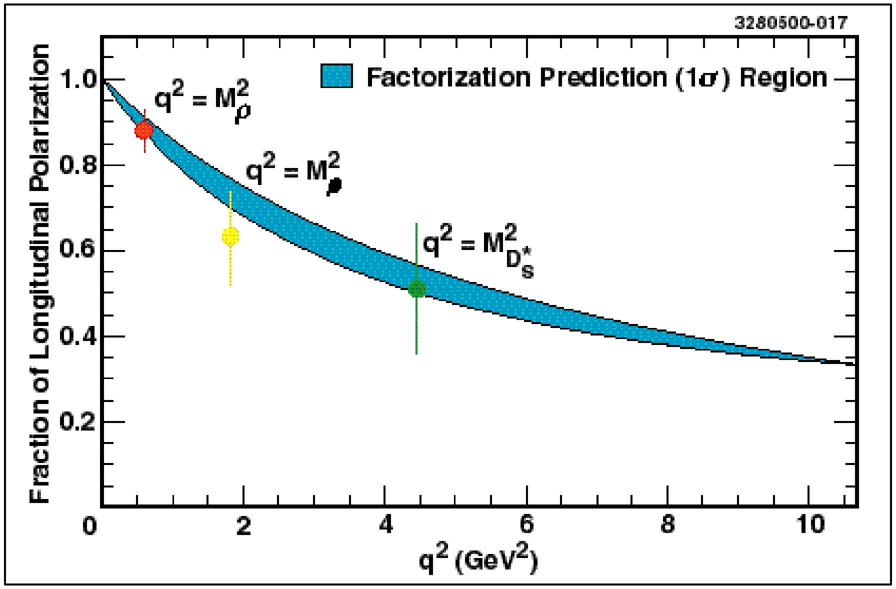
Using $B\,(\rho'^-\to\omega\pi^-)=39\%$ $\Rightarrow$ $f_{\rho'} = 167 \pm 23\,\text{MeV}$

Extending q^2: $B \to D^* D_s^*$



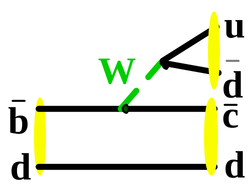
Final State	B(%)
$D^{*+} D_s^-$	1.10±0.18±0.10±0.28
$D^{*+} D_s^{*-}$	1.82±0.37±0.24±0.46
$D^{(*)+} D_s^{**0}$	2.73±0.78±0.48±0.68

D^{*+} +	Γ_L/Γ (%)
ρ^-	87.8±5.3
ρ'^-	63 ± 9
D_s^-	50.6±13.9±3.6

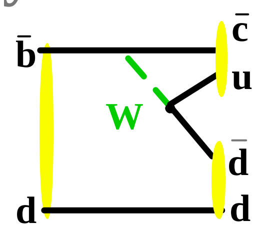


Charged B Decay and Interference

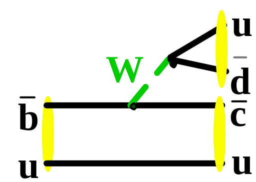
B^0 Decay **Decay**



B^0 ->D^-p^+



B^0 ->D^0p^0



B^+ ->D^0p^+

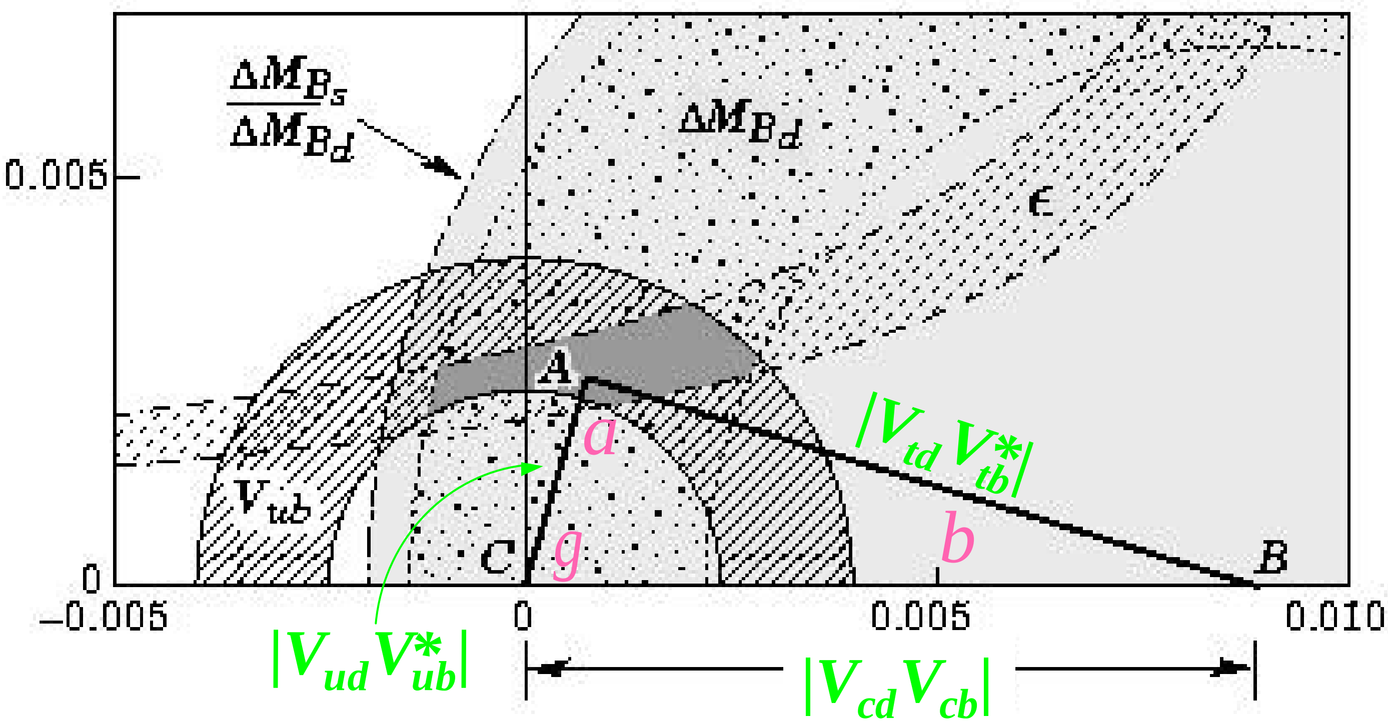
Different final states **Interference**

BSW: a_1 a_2 $a_1 + z\, a_2$

Mode	B^0 (x10^{-3})	B^+ (x10^{-3})
Dπ	3.0+/-0.4	5.3+/-0.5
Dρ	7.9+/-1.4	13.4+/1.8
Da_1	6.0+/-3.3	
Dρ’	2.8+/-0.6	4.1+/-0.8
D*π	2.8+/-0.2	4.6+/-0.4
D*ρ	6.8+/-3.4	15.5+/-3.1
D^*a_1	13+/-2.7	19+/-5
D*ρ’	2.9+/-0.5	4.1+/-0.8

- **a_1, a_2 are phenomenological constants**
- **process dependent**
- **great success in charm decay:**
  - **destructive interference**
  - **smaller $G_{Hadronic}$ for D^+**
  - $t_{D+} >> t_{D0}$

CKM, rare B Decays and CP Asymmetries



- A new measurement of V_{cb}
- V_{ub} update
- New rare decays
- CP Asymmetries

A new measurement of V_{cb}

The differential decay rate, for $B \to D^* l \nu$ is:

$$\frac{d\Gamma}{dw} = \frac{G_F^2}{48\pi^3} |V_{cb}|^2 |F(w)|^2 G(w)$$

w is the Lorentz γ factor of the recoiling D*.
It is a function of masses and q^2. (1 ? w ? 1.5)
w = 1 is the "zero recoil" point.

G(w) is a known kinematic function.

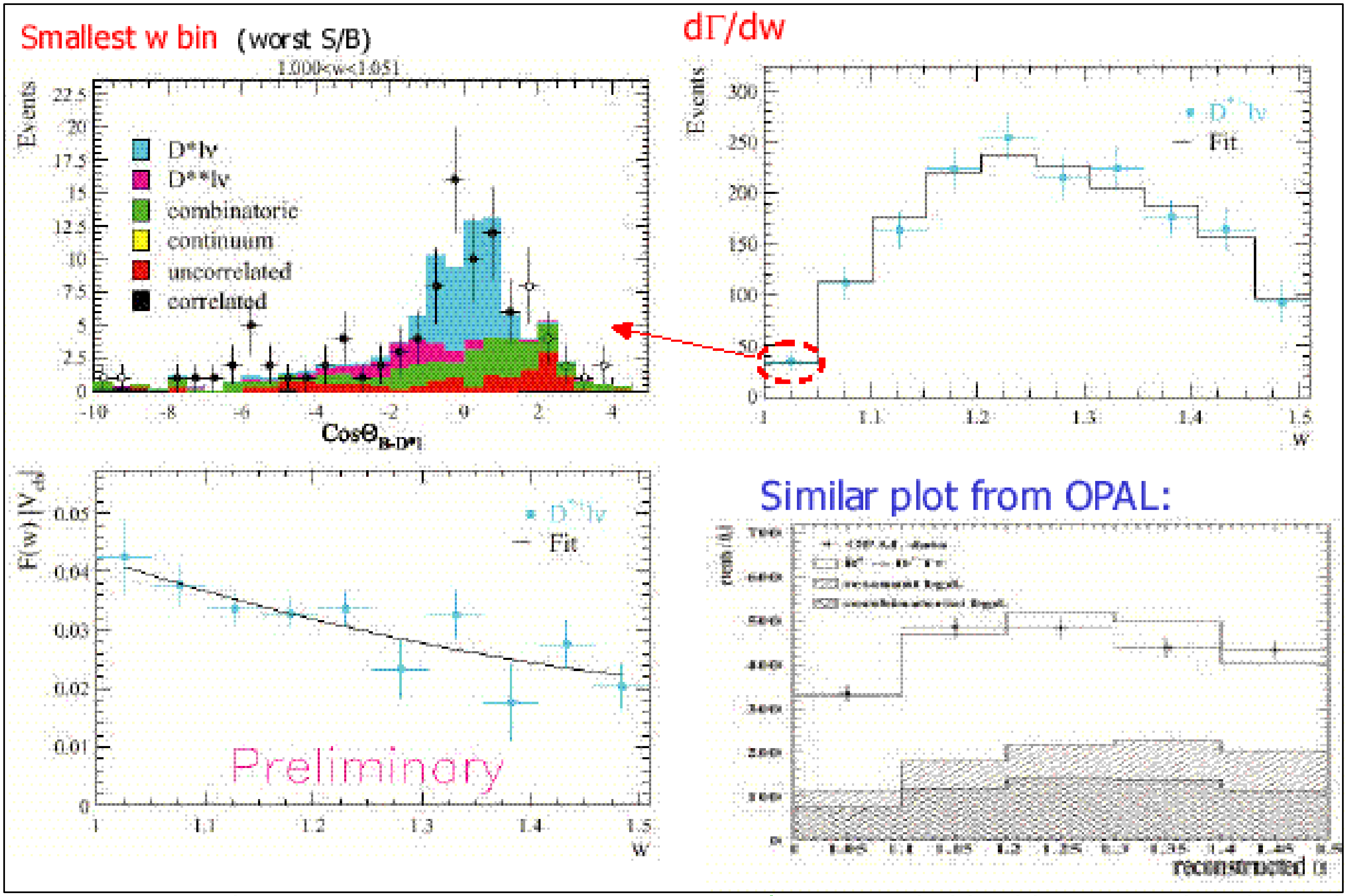
F(w) is the form factor. HQET constrains it.
As $m_{b,c} \to \infty$, $F(1) \to 1$.
For finite m, the corrections are $O(1/m^2)$.

Two methods:

- Extrapolate differential rate to w = 1.
- Integrate the total $B(b \to X_c l \nu)$.

The first method is less sensitive to F(w) systematics, but has worse statistics.

Results


Smallest w bin (worst S/B)
1.000<w<1.051
Events
D*lν
D**lν
combinatoric
continuum
uncorrelated
correlated
CosΘ_B-D*l
dΓ/dw
Events
D*lν
Fit
w
F(w) |V_cb|
D*lν
Fit
Preliminary
w
Similar plot from OPAL:
reconstructed ω

Is there a problem?

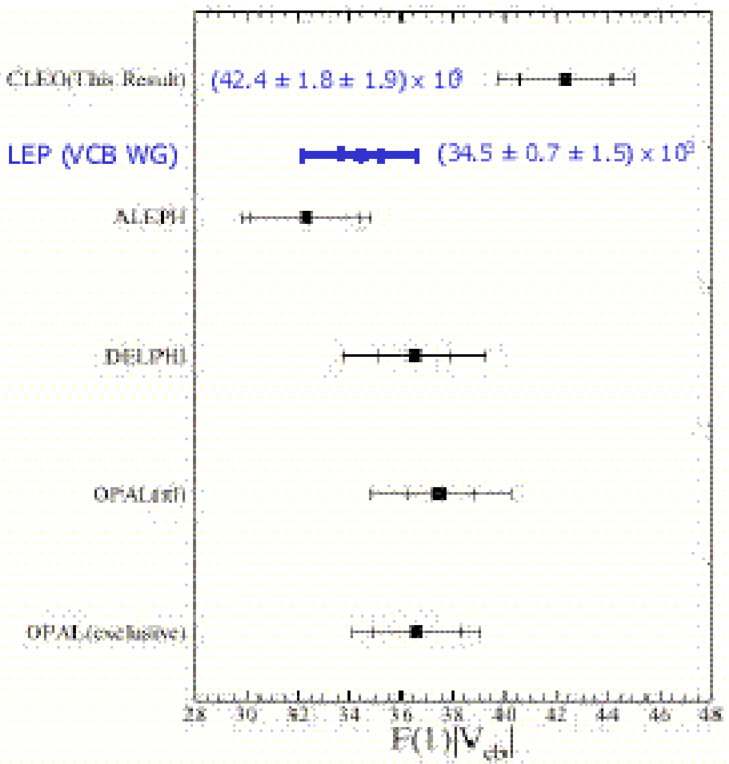
CLEO:

$F(1)|V_{cb}| = (42.4 \pm 1.8 \pm 1.9) \times 10^{-3}$ using: $F(1) = 0.913 \pm 0.042$

$BR(D^{*+}l\nu) = (5.66 \pm 0.29 \pm 0.33)\%$ yields: $|V_{cb}| = (46.4 \pm 2.0 \pm 2.1 \pm 2.1) \times 10^{-3}$

F(1) uncertainty

There appears to be a problem:



This result is strongly correlated with the measured slope, ρ^2, of F(w):

CLEO: $\rho^2 = 1.67 \pm 0.11 \pm 0.22$

LEP: $\rho^2 = 1.01 \pm 0.08 \pm 0.16$

Note, LEP and CLEO now agree about the total semileptonic BR.

Waiting for a V_{ub} update...

- Exclusive (B -> $\rho l \nu$ or $\pi l \nu$) [CLEO]

  $|V_{ub}| = (3.25 +/- 0.14^{+0.21}_{-0.29} +/- 0.55) \times 10^{-3}$

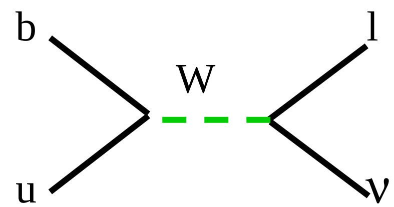
- Inclusive (b -> $X_u l \nu$) [LEP, CLEO]

  $|V_{ub}| / |V_{cb}| = 0.8 +/- 0.2$

- Rare hadronic decays (e.g. B->$\pi\pi$) (seen)
- B->$D_s^{(*)}\pi^{+(0)}$ (not seen)
- B -> $\tau\nu$

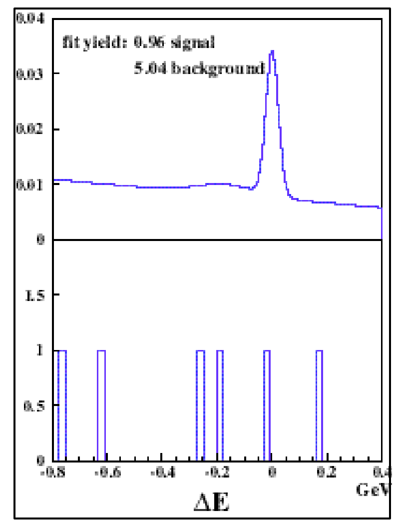
Pure leptonic decays: B -> τν

$$BR(B^+ \rightarrow l^+ \nu) = \frac{G_F^2 m_B m_l^2}{8\pi}\left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 \, |V_{ub}|^2 \, \tau_B$$



Standard Model: B -> τν ~ (0.2-1) x 10^{-4}

Idee: fully reconstruct on B, look for τ + missing energy



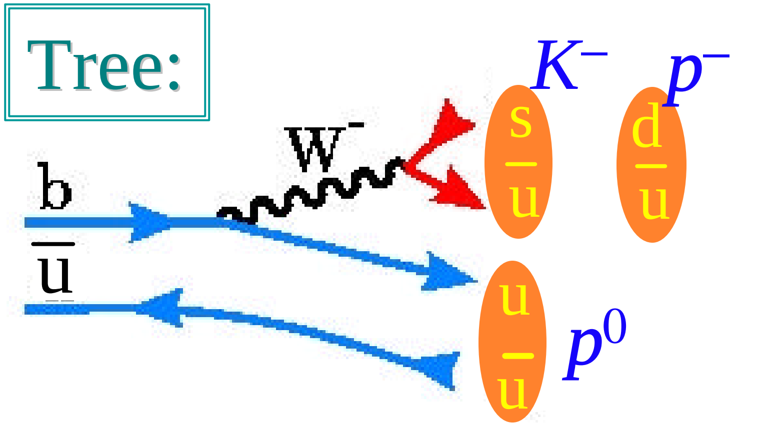
Using 9.7 x 106 BB events we find

BR(B -> τν) < 8.4 x 10^{-4}

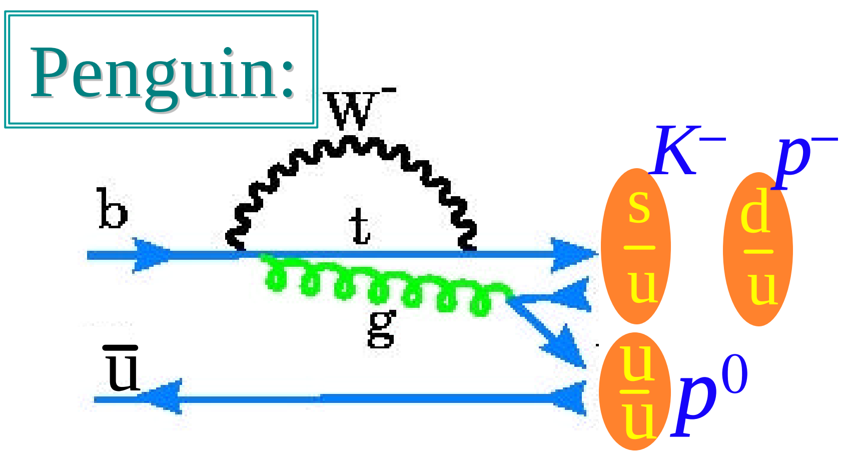
Bonus:

BR(B -> Kνν) < 2.4 x 10^{-4}

Rare B Decay



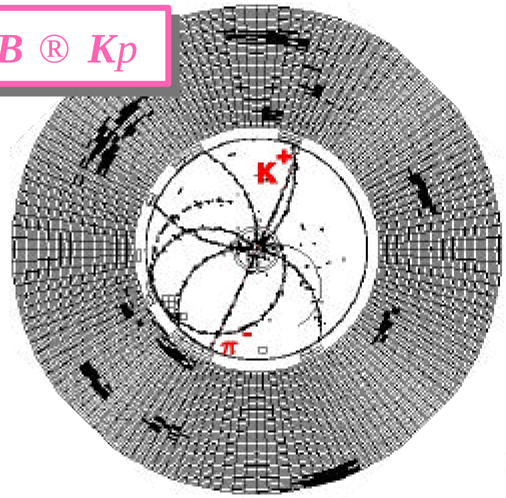
- Tree decays $b \rightarrow u$ vs. $b \rightarrow c$ suppressed by $|V_{ub}|^2/|V_{cb}|^2 \sim 0.01$
- Additional $|V_{us}|^2/|V_{ud}|^2 \sim 0.04$ for K^-
- Expect tree dominantly $b \rightarrow u\bar{u}d$.



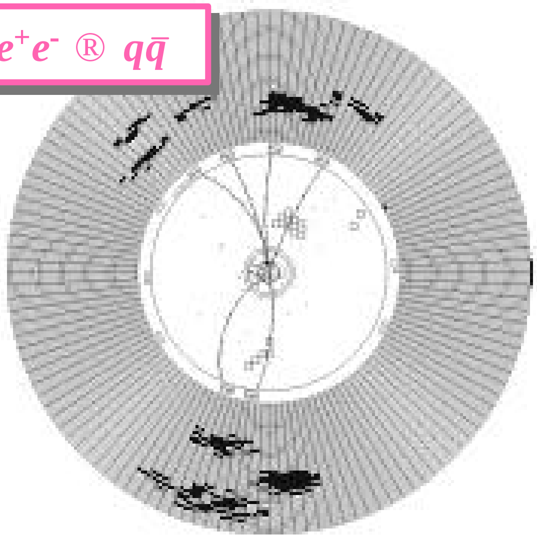
- Decays $b \rightarrow s,d$ GIM-suppressed
- Loop diagram $\propto (m_t/m_W)^2$.
- $|V_{td}|^2/|V_{ts}|^2 \sim 0.01$
- Expect penguins dominantly $b \rightarrow u\bar{u}s$.

$B \to K^+p^-/p^+p^-$ Topology

B ® Kp



e^+e^- ® $q\bar{q}$

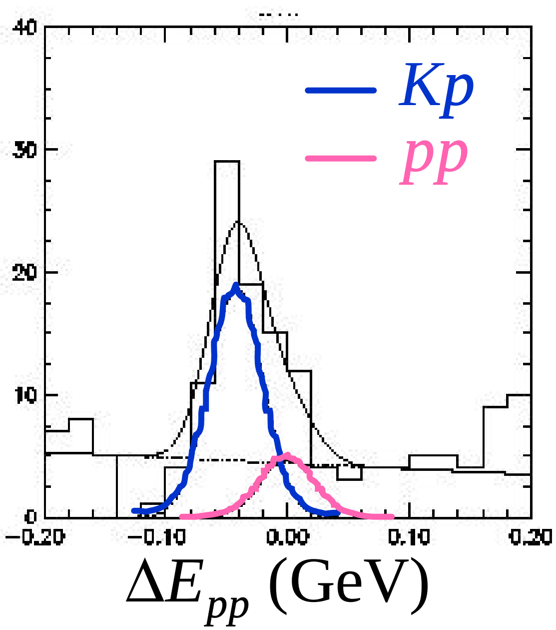


- $P_{\text{daughter}} \sim 2.55 - 2.85$ GeV/c
  (higher than for $b \to c$ decays)
- Major background from $e^+e^- \to q\bar{q}$ "continuum"
- Continuum events are "jetty" in topology
- $P_B \sim 300$ MeV/c $\Rightarrow B\bar{B}$ events "spherical"
- Continuum suppression from ML fit to several kinematic and topological variables (more efficient).
- Continuum suppression factor of ~ 10^6, efficiency for Kp/pp of ~ 40%

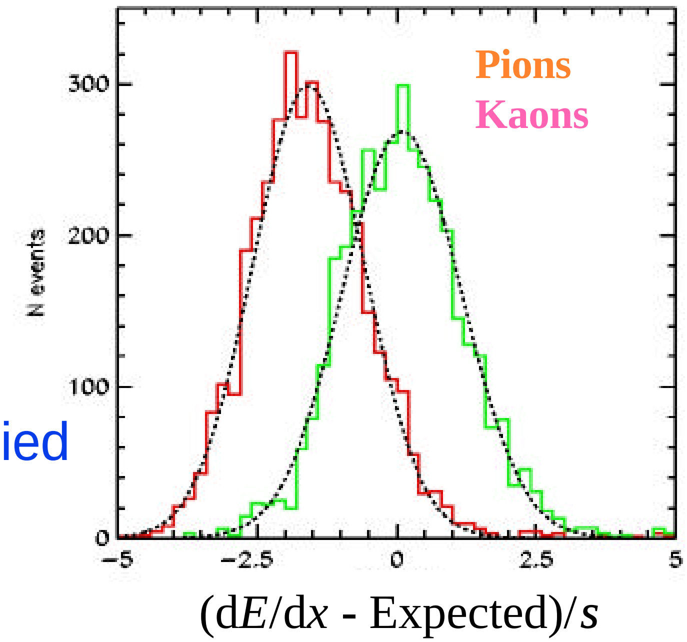
K/p Separation

- *Kp* vs. *pp* from *dE/dx* in drift chamber
  - Resol. confirmed with $D^{*-} \rightarrow D^0\pi^-$, $D^0 \rightarrow K^-\pi^+$
- Also separation from kinematics:

$$\Delta E_{pp} = E_p + E_p - E_{beam}$$

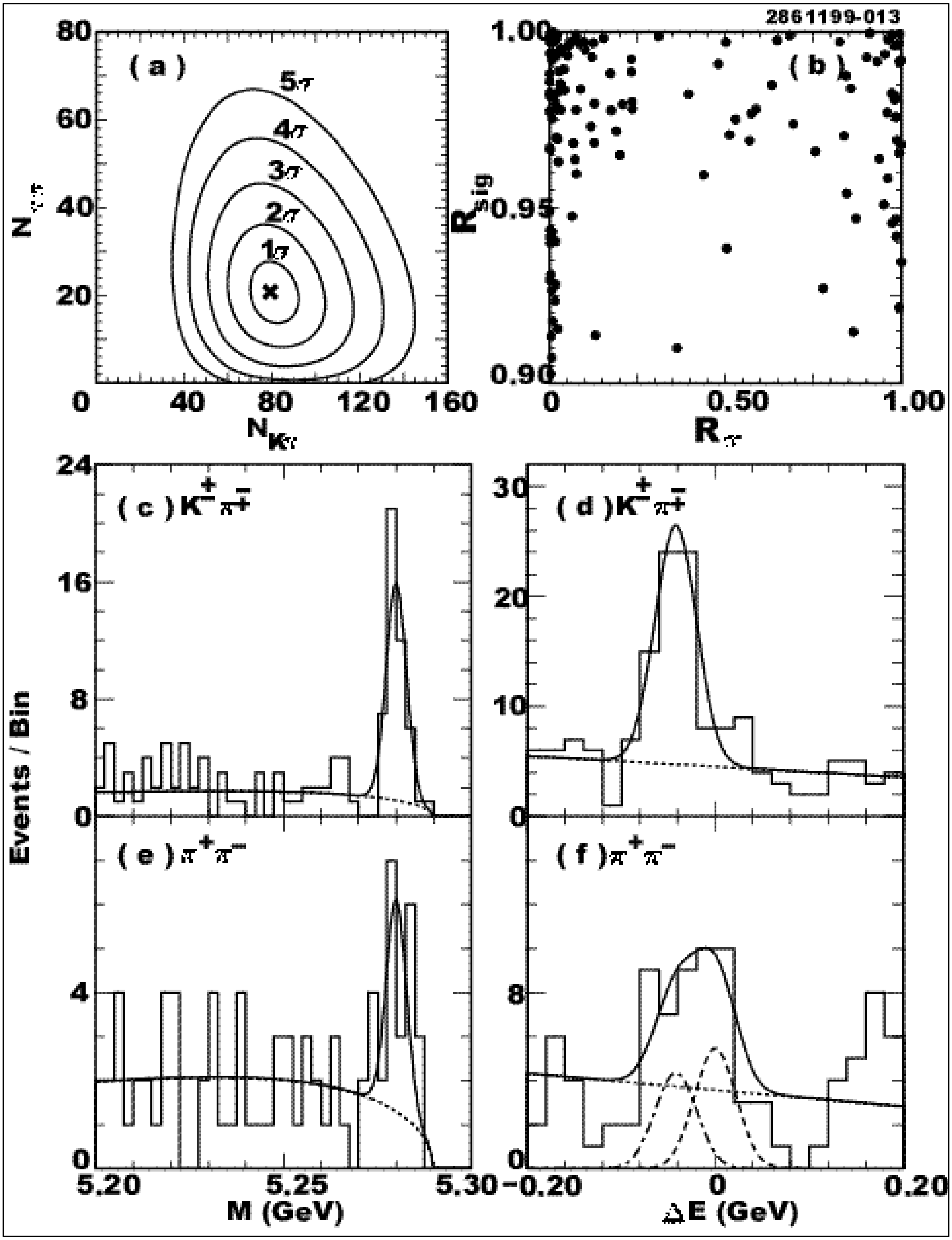


- ΔE resolution studied with $D^0 \rightarrow K^-\pi^+(\pi^0)$ mass resolutions



	$s_{\Delta E}$	ΔE	dE/dx
CLEO II	25 MeV	1.7s	1.7s
CLEO II.V	20 MeV	2.1s	2.0s

Fit Results for $B \to K p$, $B \to p p$



$B \to Kp$, $B \to pp$ Summary

	Signal (events)	# s	e (%)	BR ($\times 10^{-6}$)
p^+p^-	$20.0^{+7.6}_{-6.5}$	4.2	48	$4.3^{+1.6}_{-1.4} \pm 0.5$
p^+p^0	$21.3^{+9.7}_{-6.5}$	3.2	39	< 12.7
p^0p^0	$6.2^{+4.8}_{-3.7}$	2.0	29	< 5.7
K^+p^-	$80.2^{+11.8}_{-11.0}$	11.7	48	$17.2^{+2.5}_{-2.4} \pm 1.2$
K^+p^0	$42.1^{+10.9}_{-9.9}$	6.1	38	$11.6^{+3.0}_{-2.7} \pm 1.4$
K^0p^+	$25.4^{+6.4}_{-5.6}$	7.6	14	$18.2^{+4.6}_{-4.0} \pm 1.6$
K^0p^0	$16.1^{+5.9}_{-5.1}$	4.9	11	$14.6^{+5.9}_{-5.1}{}^{+2.4}_{-3.3}$
K^+K^-	$0.7^{+3.4}_{-0.0}$	0.0	48	< 1.9
K^+K^0	$1.4^{+2.4}_{-1.3}$	1.1	14	< 5.1

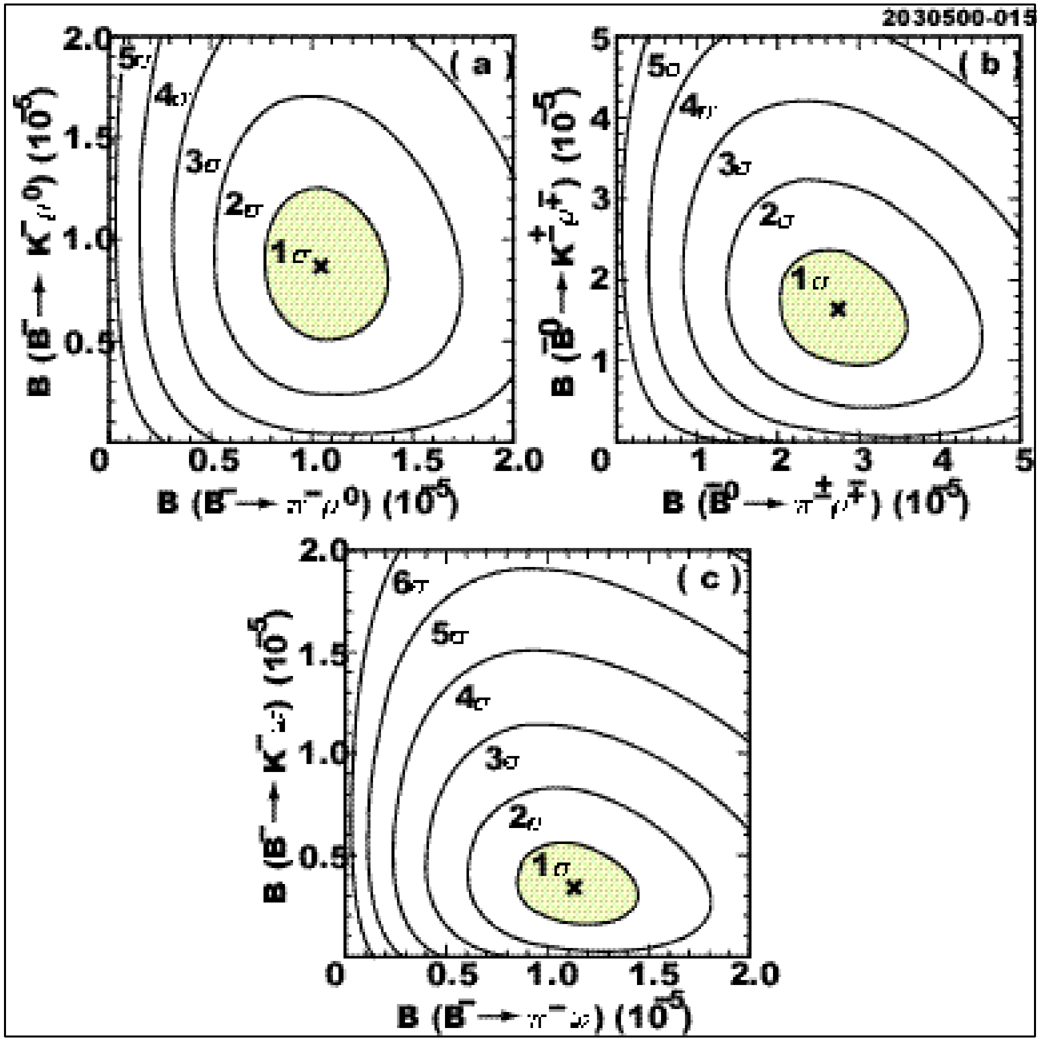
Exclusive b → u Transitions

- Many hadronic b → u transitions observed
- New study includes 14 channels (hep-ex/0006008)
- In general - good agreement with theory
- Full Dalitz analyses could determine α and γ

Mode	Yield	Signif.	$\mathcal{B}$ (10^{-6})	Theory
$B^- \to \pi^- \rho^0$	$29.8^{+9.3}_{-9.6}$	5.4σ	$10.4^{+3.3}_{-3.4} \pm 2.1$	0.4 - 13.0
$B^- \to K^- \rho^0$	$22.4^{+10.7}_{-9.1}$	3.7σ	< 17	0.0-6.1
$B^- \to \pi^0 \rho^-$	$22.7^{+8.4}_{-7.4}$	5.1σ	< 43	3.0 - 27.0
$B^- \to \pi^0 K^{*-}$	$2.6^{+4.2}_{-2.6}$	1.0σ	< 31	0.5 - 24.0
$B^- \to \pi^- \omega$	$28.5^{+8.2}_{-7.3}$	6.2σ	$11.3^{+3.3}_{-2.9} \pm 1.4$	0.6 - 24
$B^- \to K^- \omega$	$7.9^{+6.0}_{-4.7}$	2.1σ	< 7.9	0.2 - 14.0
$B^- \to \pi^- K^{*0}$	$13.4^{+6.2}_{-5.3}$	3.6σ	< 16	3.4 - 13.0
$B^- \to K^- K^{*0}$	$0.0^{+2.2}_{-0.0}$	0.0σ	< 5.3	0.2 - 1.0
$B^0 \to \pi^\pm \rho^\mp$	$31.0^{+10.4}_{-8.3}$	5.6σ	$27.6^{+8.4}_{-7.4} \pm 4.2$	12 - 93
$B^0 \to K^\pm \rho^\mp$	$16.4^{+7.8}_{-6.6}$	3.5σ	< 32.3	0. 0- 12.0
$B^0 \to \pi^0 \rho^0$	$5.4^{+6.5}_{-4.8}$	1.2σ	< 5.5	0.0 - 2.5
$B^0 \to \pi^0 \omega$	$1.5^{+3.5}_{-1.5}$	0.6σ	< 5.5	0.0 - 12.0
$B^0 \to K^0 \omega$	$7.0^{+3.8}_{-2.9}$	3.9σ	< 21	0.0 - 17.0
$B^0 \to \pi^0 K^{*0}$	$0.0^{+3.0}_{-0.0}$	0.0σ	< 3.6	0.7 - 6.1

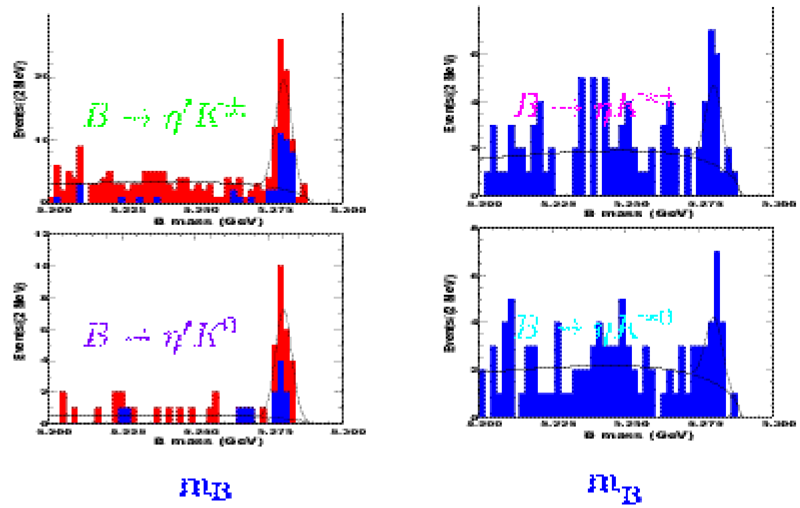
Likelihood Contours

- $B \rightarrow r^{+}p/rK$ and $B \rightarrow r^{0}p/rK$ fitted simulataneously
- $BR(B \rightarrow r^{+}p)$/BR($B \rightarrow r^{0}p)$ smaller than expected (>4)



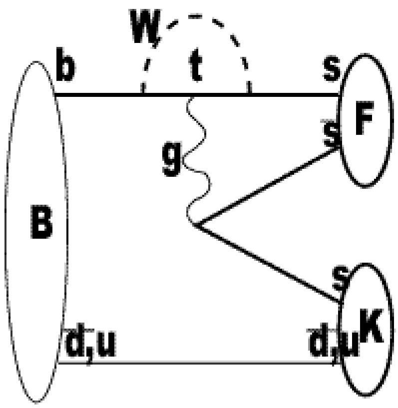
Modes with h and h'

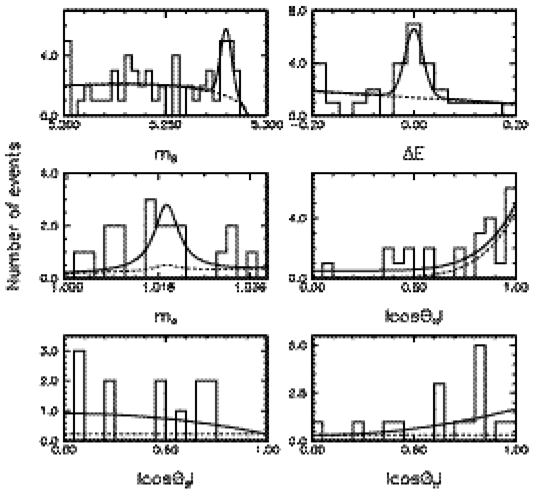
Mode	Signif.	$\mathcal{B}$ (10^{-6})
$B^+ \to \eta' K^+$	10.8σ	$80^{+10}_{-9} \pm 7$
$B^0 \to \eta' K^0$	11.7σ	$89^{+18}_{-16} \pm 9$
$B^+ \to \eta' \pi^+$	0.0σ	< 12
$B^0 \to \eta' \pi^0$	0.0σ	< 5.7
$B^+ \to \eta' K^{*+}$	1.8σ	< 35
$B^0 \to \eta' K^{*0}$	1.8σ	< 24
$B^+ \to \eta' \rho^+$	2.4σ	< 33
$B^0 \to \eta' \rho^0$	0.0σ	< 12
$B^+ \to \eta K^+$	0.8σ	< 6.9
$B^0 \to \eta K^0$	0.0σ	< 9.3
$B^+ \to \eta \pi^+$	0.6σ	< 5.7
$B^0 \to \eta \pi^0$	0.0σ	< 2.9
$B^+ \to \eta K^{*+}$	4.8σ	$26.4^{+9.6}_{-8.2} \pm 3.3$
$B^0 \to \eta K^{*0}$	5.1σ	$13.8^{+5.5}_{-4.6} \pm 1.6$
$B^+ \to \eta \rho^+$	1.3σ	< 15
$B^0 \to \eta \rho^0$	1.3σ	< 10



PRL 80, 3710 (1998) + PRL 85, 520 (2000)

Pure Penguins: $B \to fK$





$BR(B^- \to \phi K^-) = (6.4^{+2.5+0.5}_{-2.1-2.0}) \times 10^{-6}$

$BR(B^0 \to \phi K^0) = (5.9^{+1.9+1.1}_{-2.9-0.9}) \times 10^{-6} \to < 1.2 \times 10^{-5}$

Combined result: $BR(B \to \phi K) = (6.2^{+2.0+0.7}_{-1.8-1.7}) \times 10^{-6}$

- Pure gluonic penguin, simple final state, sensitive to $\sin 2\beta$
- Theoretical uncertainties are large
  - Deshpande+He: inclusive $B \to \phi X_s \sim (0.6 - 2.0) \times 10^{-4}$
  - ϕK fraction of $\phi X_s \sim 10\%$

arg(V_{ub}) (= *g*) from Decay Rates

- Fleischer-Mannel (*Phys. Rev.* **D57**, 2752(1998))

$$R \equiv \frac{\Gamma(B^0 \to K^- \pi^+)}{\Gamma(B^+ \to K^0 \pi^+)} \geq \sin^2 g \qquad \text{CLEO:} \qquad R = 1.01 \pm 0.26$$

- Neubert-Rosner (*Phys. Lett.* **B441**, 403 (1998))

$$R_* \equiv \frac{\Gamma(B^+ \to K^0 \pi^+)}{2\Gamma(B^+ \to K^+ \pi^0)} \qquad (1\text{-}R_*)/e_{3/2} \leq |d_{EW} - \cos g|$$

$$0.58 \pm 0.74 \leq |\,(0.64 \pm 0.15) - \cos g|$$

- Also model-dependent fit to many CLEO branching ratios of *pp*, *Kp*, *rp*, *wp* (Wuerthwein *et al.* hepex/9910014):

  84 < *g* < 154 (90% C.L.)

CP Asymmetries

- Measure *B* and $\overline{B}$ reactions described by two amplitudes:
  - $\Gamma(B \to f) = | a_1 e^{i(f_1 + d_1)} + a_2 e^{i(f_2 + d_2)} |^2$
  - $\overline{\Gamma}(\overline{B} \to \overline{f}) = | a_1 e^{i(-f_1 + d_1)} + a_2 e^{i(-f_2 + d_2)} |^2$
- CP asymmetry from strong and weak phase differences
  - $\Delta \equiv (\Gamma - \overline{\Gamma}) / (\Gamma + \overline{\Gamma}) \propto \sin(f_1 - f_2)\sin(d_1 - d_2)$
- Depends upon comparable magnitudes as well
- CLEO can measure decays that are sensitive to $g = \arg(V_{ub}{}^*)$
  - $B^+ \to K^+ p^0$, $B^+ \to K^0 p^+$, $B^+ \to K^+ h'$

A_{cp} Expectations

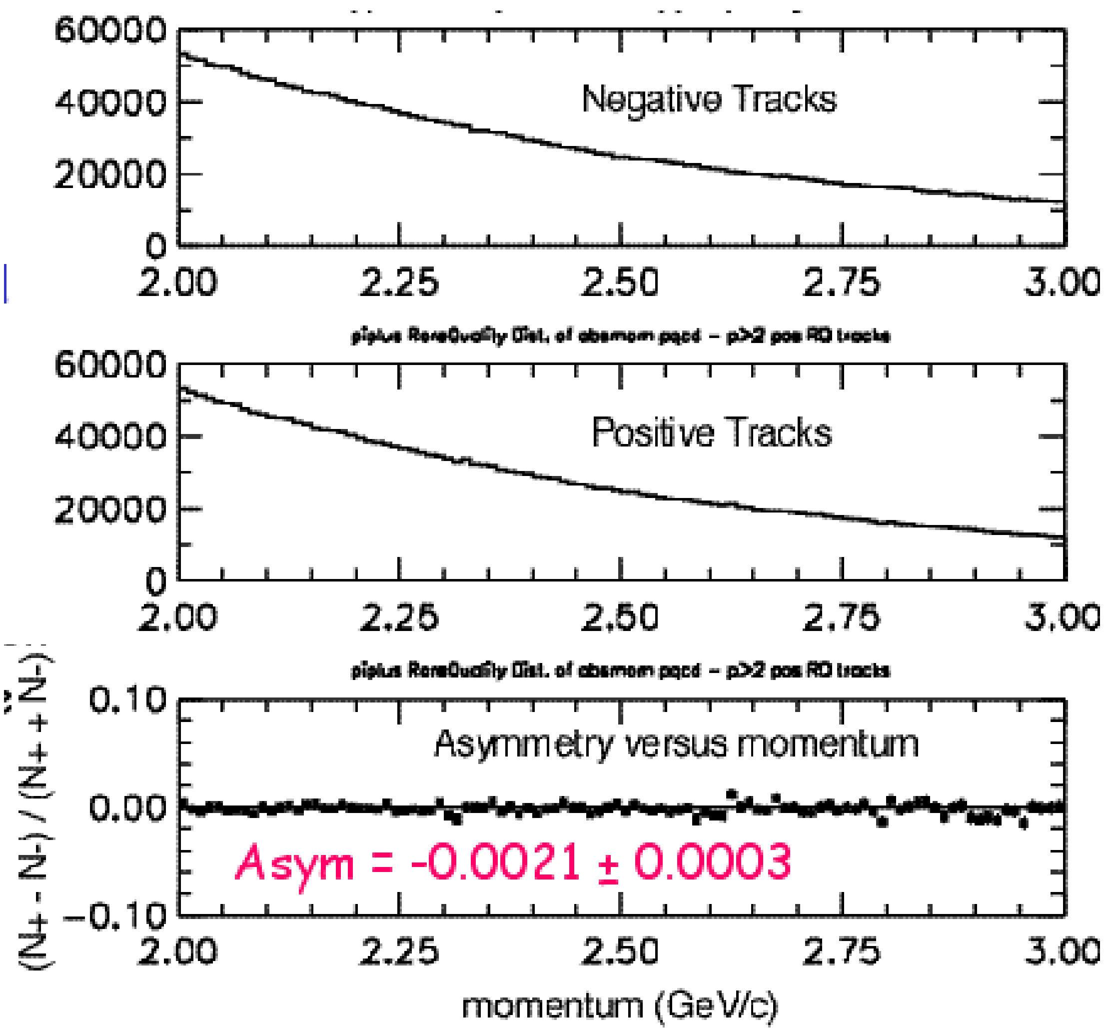
- Factorization model calculations (no FSI interactions)
  Ali, Kramer, Liu, hep-ph/9805403
  - K^+p^+ 0.04 - 0.11
    - » K^+p^0 0.03 - 0.09
  - K^0p^+ 0.01
    - » K^+h' 0.02 - 0.06
  - wp^+ -0.12 - +0.02

- Final state interactions may boost A_{CP} ~ 20 - 40%.
  - He et al, *Phys. Rev. Lett*. **81**, 5738 (1998)
  - Neubert, JHEP 9902, 014 (1999)
  - Deshpande et al., *Phys. Rev. Lett*. **82**, 2240 (1999)

- New physics could boost A_{CP} ~ 40 - 60%.
  - He *et al.*, hep-ph/980982

Experimental Bias(es)

- *B* flavor tagged by high momentum track
- Must demonstrate reconstruction not charge dependent.
- Charge difference in K^-N and K^+N cross sections
- Track reconstruction difference confirmed in Monte Carlo ~ 0.002



CP Asymmetry Results

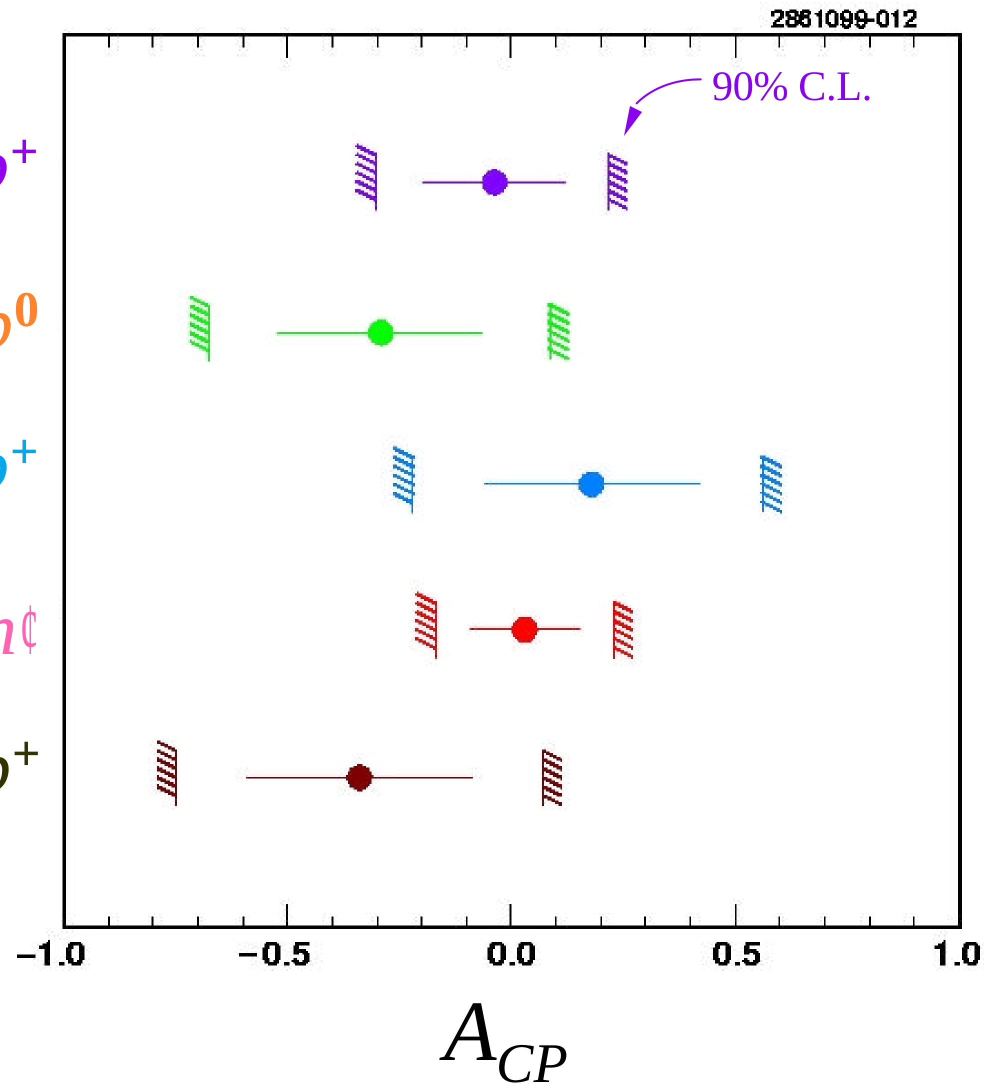
$80.2^{+11.8}_{-11.0}$ events — $K^- p^+$

$42.1^{+10.9}_{-9.9}$ events — $K^+ p^0$

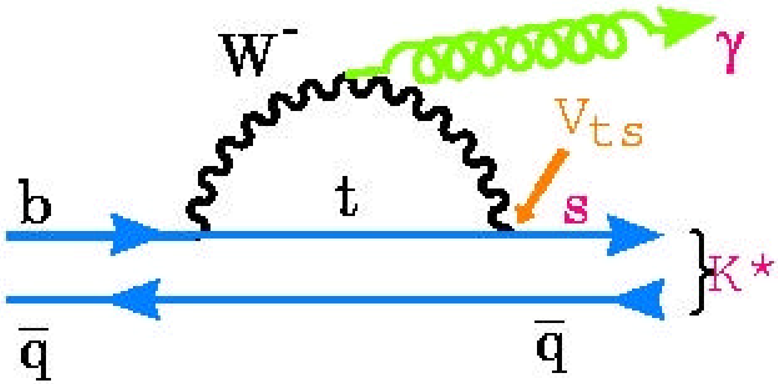
$25.2^{+6.4}_{-5.6}$ events — $K^0 p^+$

101^{+13}_{-12} events — $K^+ h¢$

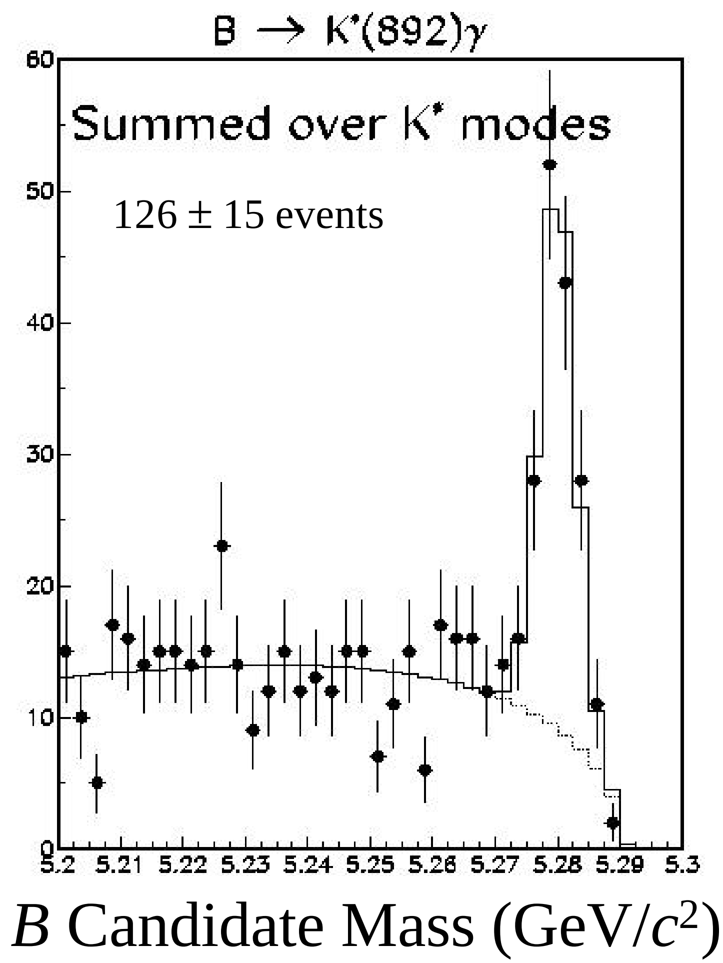
$28.5^{+8.2}_{-7.3}$ events — $w p^+$



~~CP~~ from New Physics?



- Penguin amplitude ∝ $|V_{ts}|$
- Other amplitudes, ~~CP~~, small in SM
- Some Higgs models introduce ~~CP~~, possibly even if $b \to sg$ rate unaffected.
  - Wolfenstein & Wu, *Phys. Rev. Lett.* **73**, 2809 (1998)
  - Asatrian & Ioannissian, *Phys. Rev.* **D54**, 5642
  - Kagan & Neubert, *Phys. Rev.* **D58**, 094012



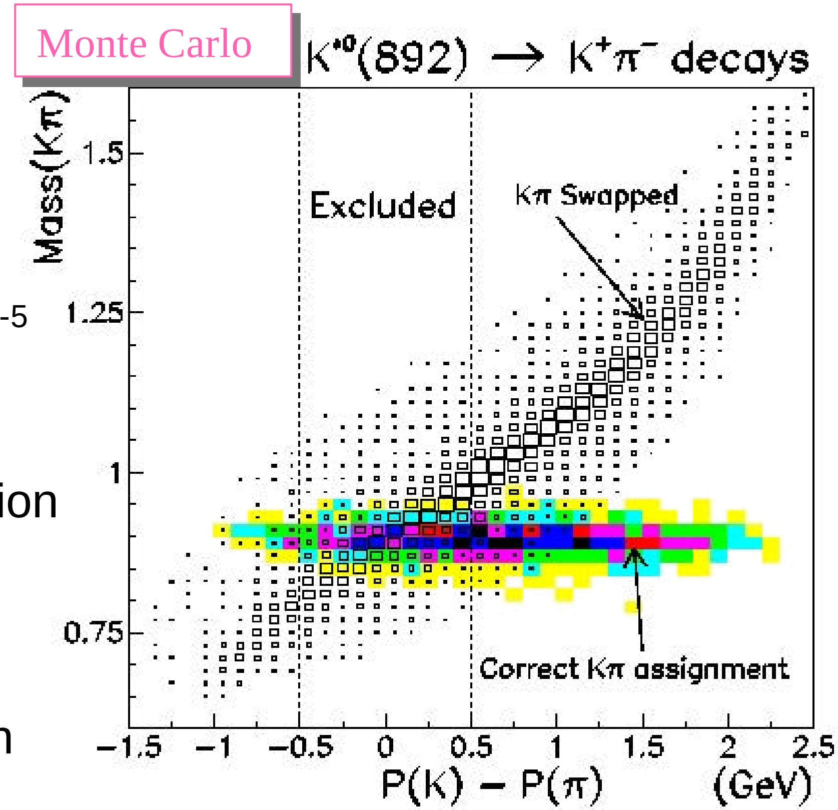
$b \to sg$ Results

- Updated branching ratio results:

$BR(B^0 \to K^{*0} g) = (4.5 \pm 0.7 \pm 0.3) \times 10^{-5}$

$BR(B^+ \to K^{*+} g) = (3.8 \pm 0.9 \pm 0.3) \times 10^{-5}$

$BR(B \to K_2^*(1430) g) = (1.6 \pm 0.55 \pm 0.13) \times 10^{-5}$



- CP asymmetry from special kinematic region for best *K/p* identificatio

  $A_{CP} = 0.08 \pm 0.13 \pm 0.03$

- Asymmetry for inclusive $b \to sg$ (based on 9.7M *BB* pairs only):

  $A_{CP} = -0.063 \pm 0.090 \pm 0.009$ or

  $-0.21 < A_{CP} < 0.09$ (90% C.L.)

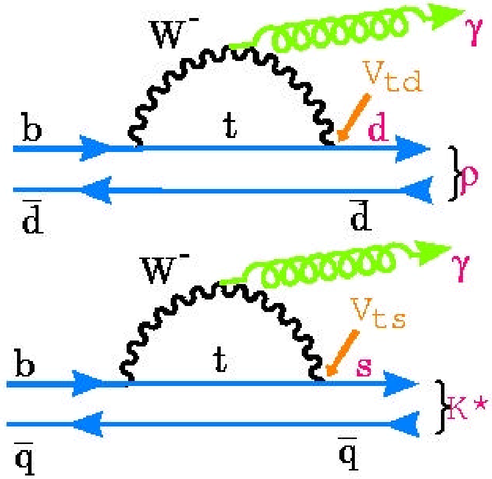
- Upper limit on $b \to d$ exclusive penguins:

  $BR(B \to (r,w)g) < \sim 10^{-5}$

Search for $b\to dg$

- Expect that $B\to rg$ also described by penguin amplitude – dominant top?

$$\frac{\Gamma(B\to rg)}{\Gamma(B\to K^{*}g)} = \frac{|V_{td}|^2}{|V_{ts}|^2}x \qquad x\sim 0.6-0.8$$



- Updated branching ratio limits:

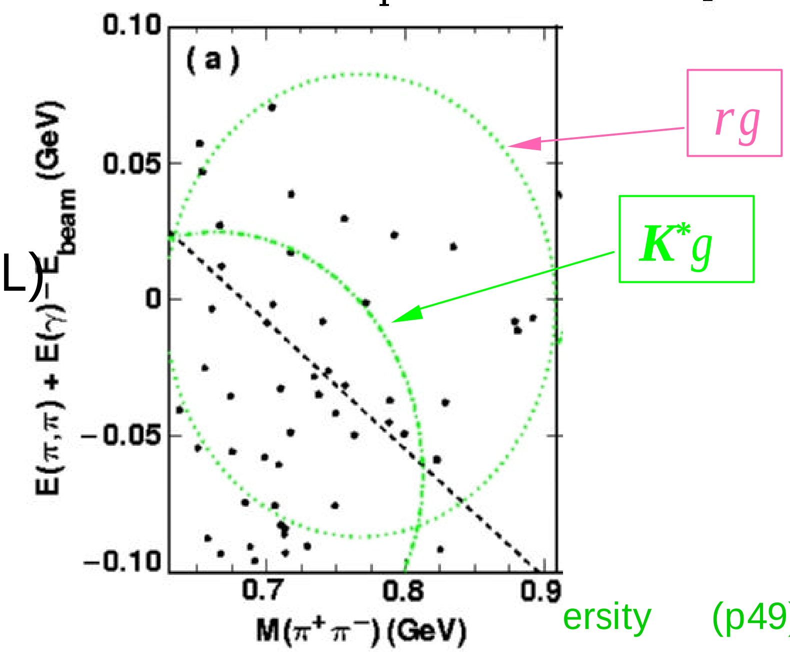
$BR(B^0\to r^0 g) < 1.7\times 10^{-5}$

$BR(B^+\to r^+ g) < 1.3\times 10^{-5}$

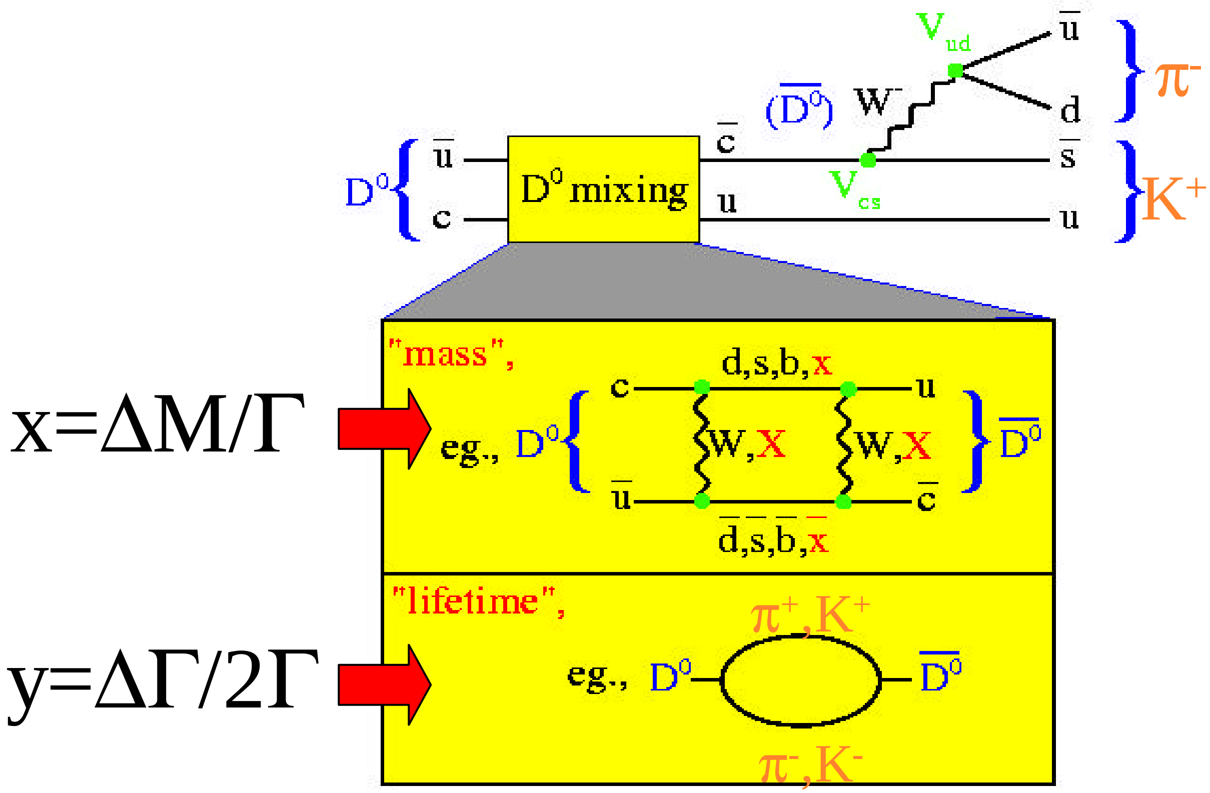
$BR(B^0\to wg) < 9.2\times 10^{-6}$

- $BR(B\to rg)/BR(B\to K^{*}g) < 0.32$ (90%CL)

- $|V_{td}/V_{ts}| < 0.72$ (90%CL)

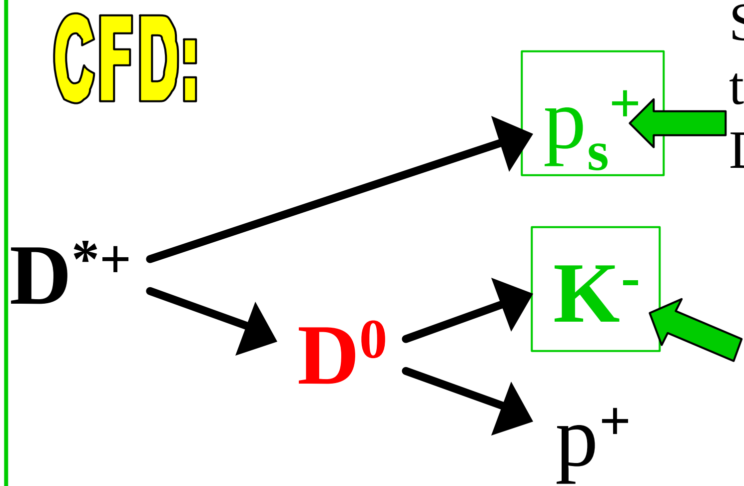


Searches for D^0-$\overline{D^0}$ Mixing



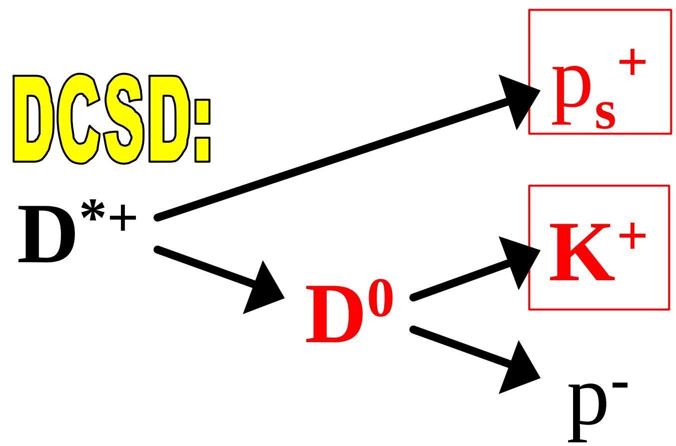
Right and Wrong-Signed D^0 Decays

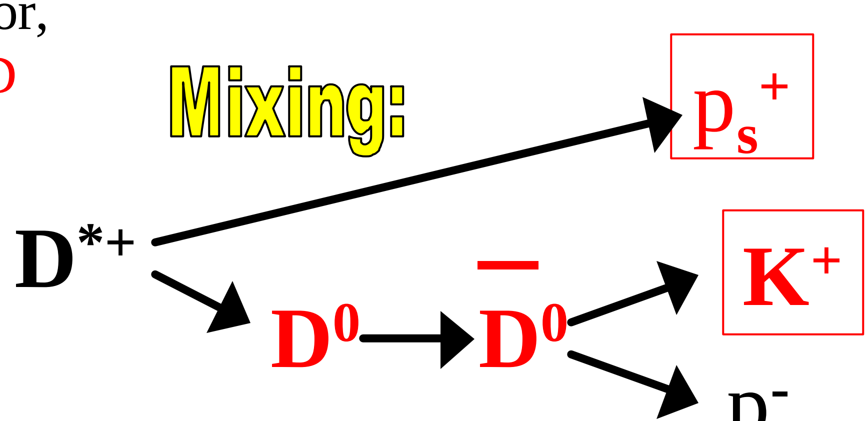
Use tagged D^0's from D^{*+} decays:



Sign of slow π tags initial D^0 flavor

Sign of K tags final D^0 flavor, unless DCSD





$D^0 \to K^+\pi^-$ Final State

Definitions:

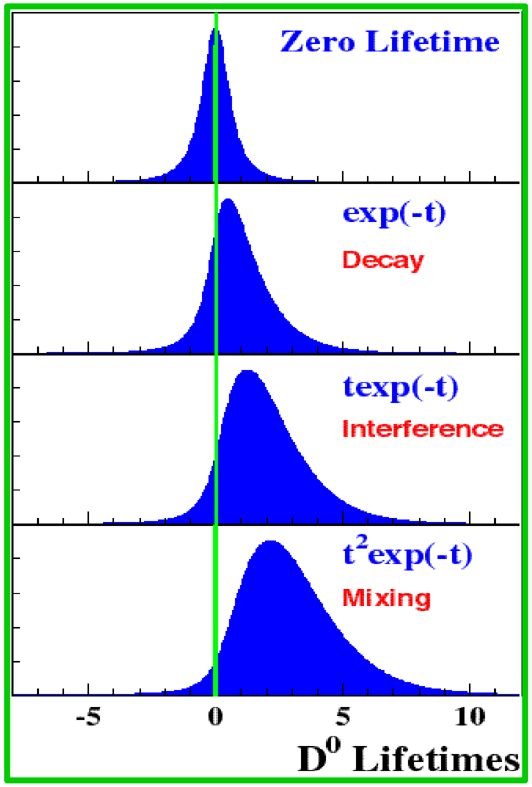
$$R \equiv \frac{\Gamma\left(D^0 \to K^+\pi^-\right)}{\Gamma\left(\overline{D}^0 \to K^+\pi^-\right)}$$

$$R = R_M + R_D + \sqrt{R_D}\, y'$$

$$R_M = \tfrac{1}{2}\left(x^2 + y^2\right)$$

Strong phase, δ, between DCSD and CFD

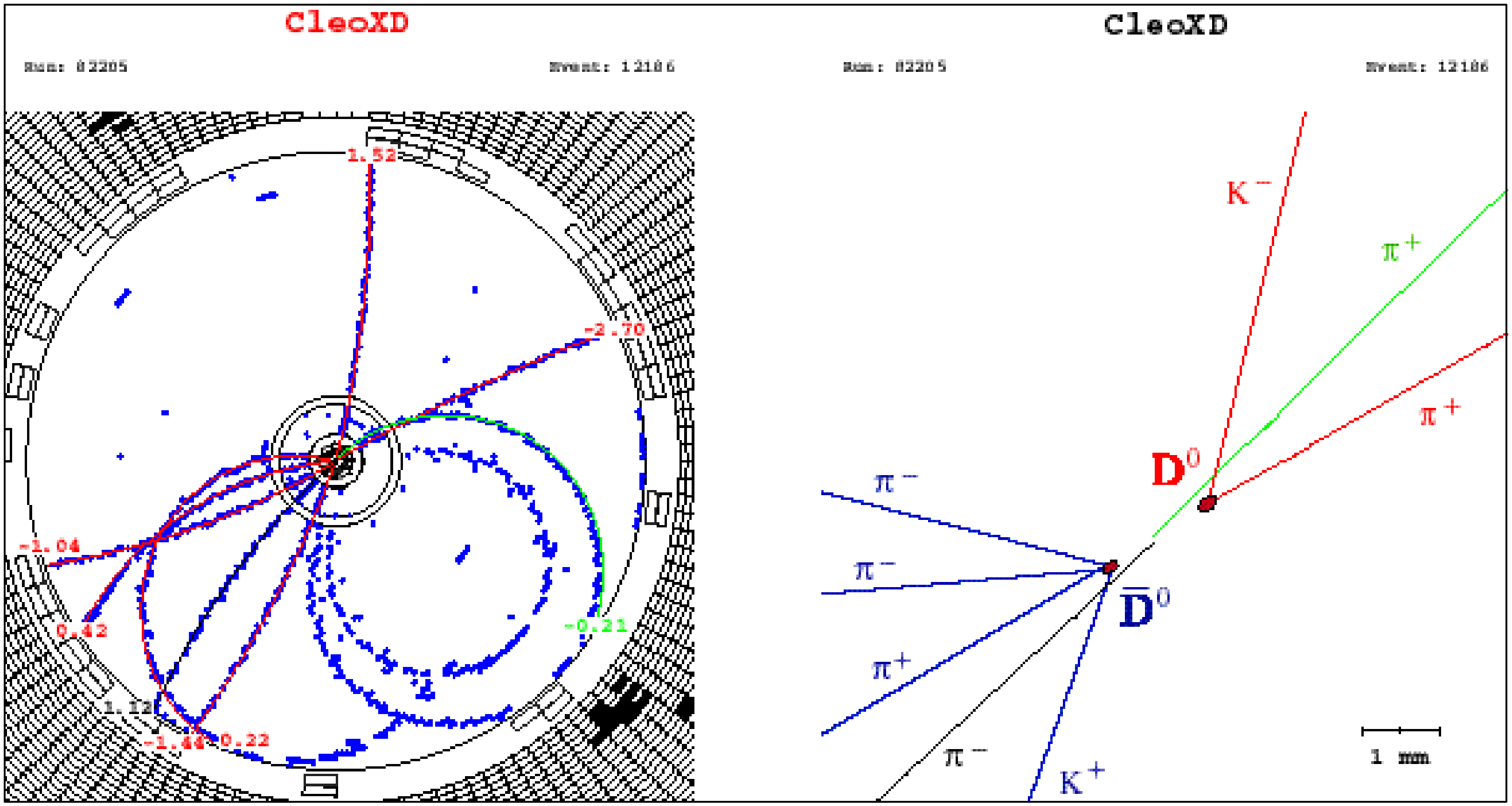
y' = y cosδ – x sinδ
x' = x cosδ – y sinδ



Time dependence of R:

$$\left(R_D + \sqrt{R_D}\, y' t + \frac{1}{4}\left[x'^2 + y'^2\right] t^2\right) e^{-t}$$

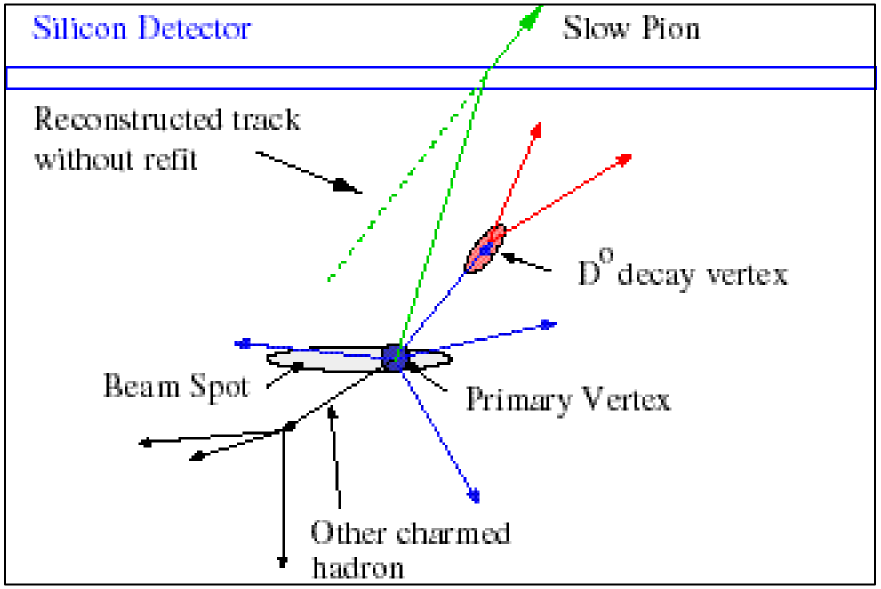
A Charm Event in CLEO II.V



Charm Reconstruction and Lifetime Method

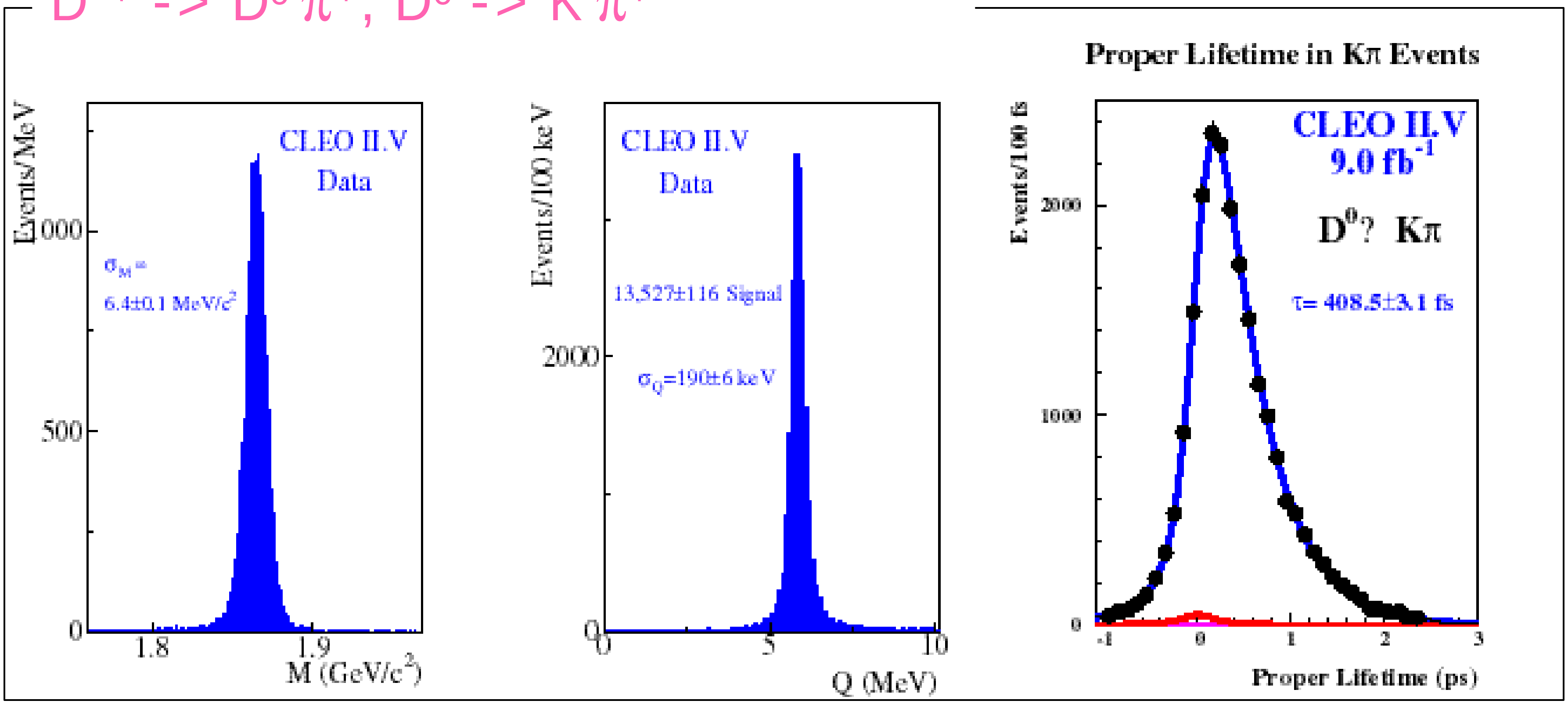
- CESR beamspot is a ribbon
  $\sigma_x \sim 350\ \mu m$
  $\sigma_y \sim 10\ \mu m$
  $\sigma_z \sim 2$ cm
- Reconstruct 3D beamspot and decay vertices
- Use only y flight information to calculate proper time

$$t_{D^0} = (y_{vtx} - y_{beamspot})\ m_{D^0}/cp_y$$



Right-signed Decays: $D^0 \to K^-\pi^+$

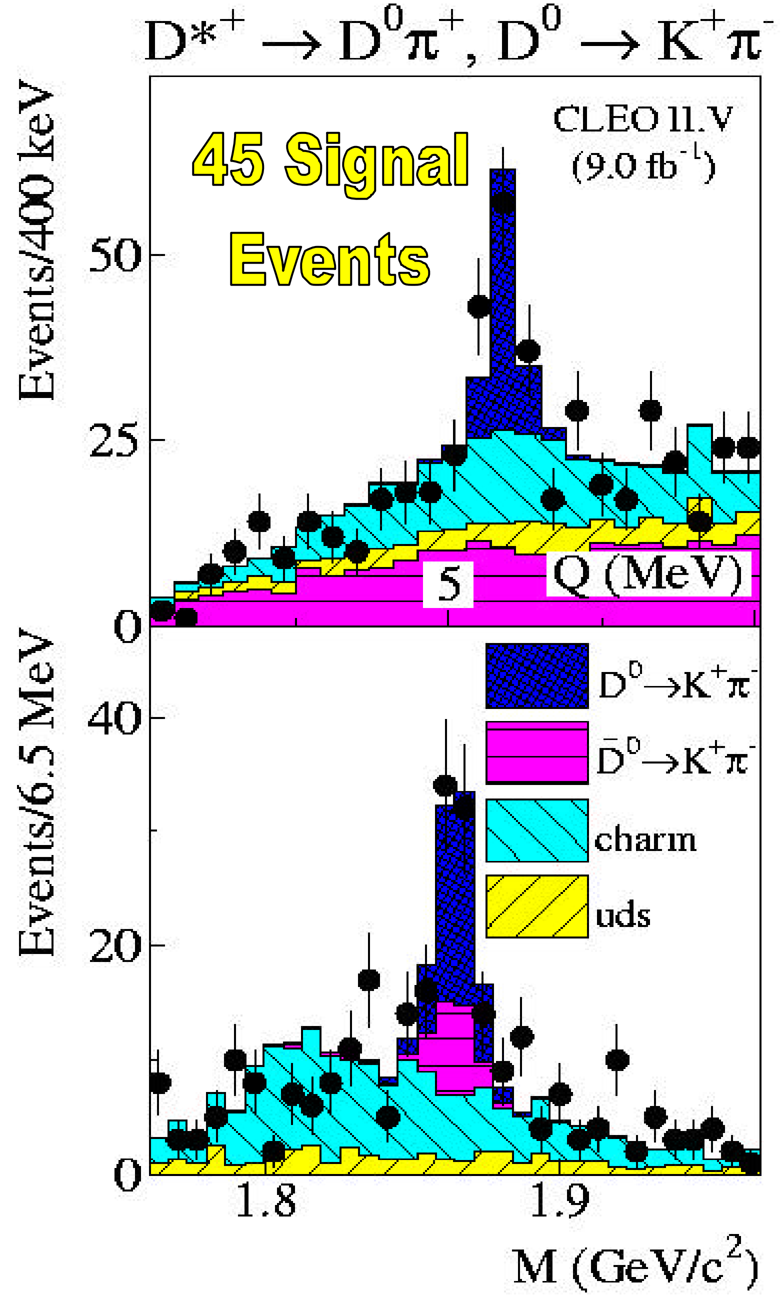
$D^{*+} \to D^0 \pi^+$, $D^0 \to K^-\pi^+$



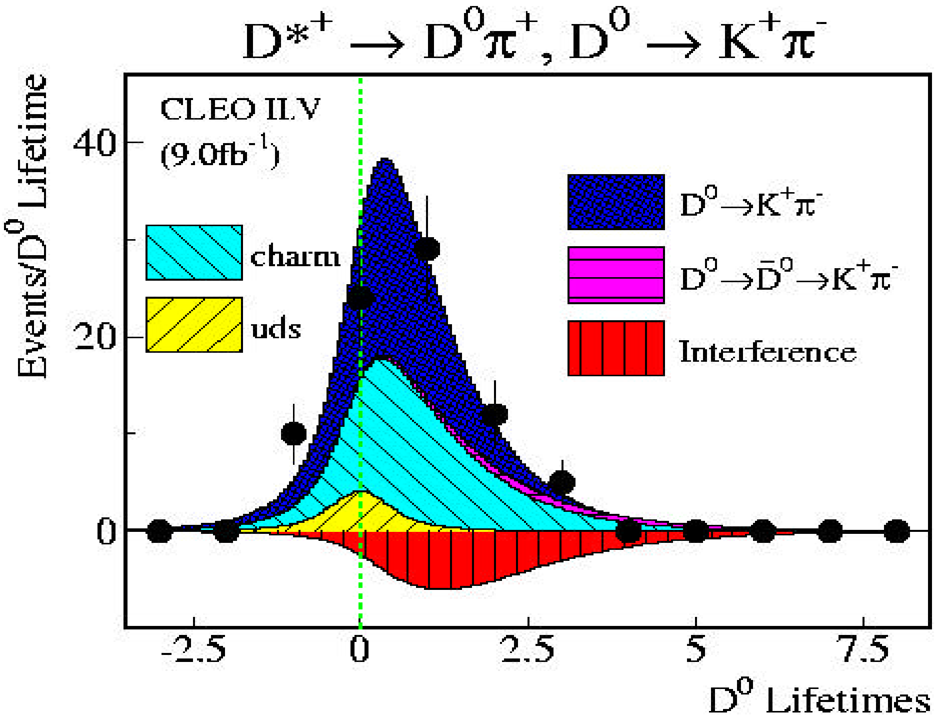
$\sigma_M = 6.4\ \mathrm{MeV}/c^2$ $\sigma_Q \sim 190\ \mathrm{KeV}$ $\sigma_\tau = 0.35\ \tau_{D^0}$

Wrong-signed Decays: $D^0 \to K^+\pi^-$

- $D^{*+} \to D^0\pi^+$ flavor tagging
- Reject CFD and SCSD candidates with $D^0 \to \pi^+K^-$, $\pi^+\pi^-$, K^+K^- mass hypotheses within 4σ of D^0 mass
- 2D Binned ML Fit in Q vs $M_{K\pi}$
- Signal Shapes WS signal shape taken from RS signal
  - Background shapes from MC
- Phys. Rev. Lett. **84**, 22 (2000)



$D^0 \to K^+\pi^-$ Decay Time Dependence



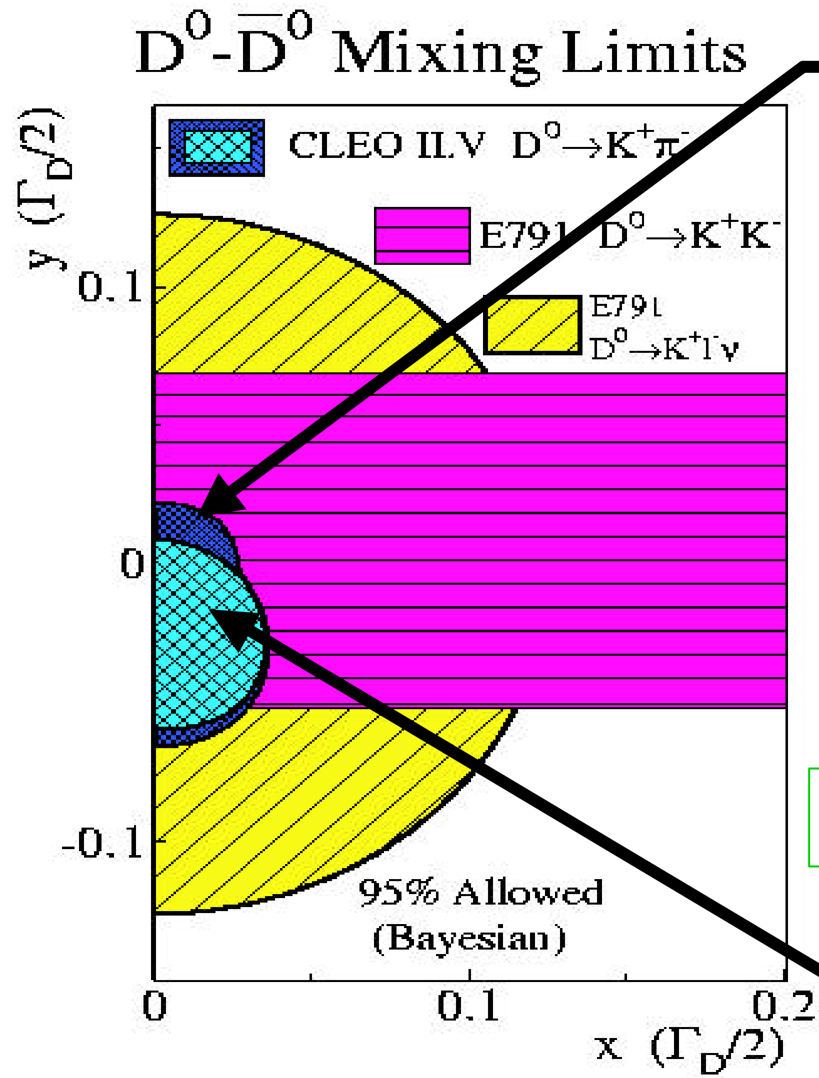
WS signal fit to function

$$\left(R_D + \sqrt{R_D}\, y' t + \frac{1}{4}\left[x'^2 + y'^2\right] t^2 \right) e^{-t}$$

combined with resolution function

Parameter	Best Fit	95% C.L.
R_D	(0.48 +/- 0.12 +/- 0.04)%	0.24% < R_D < 0.71%
y'	$(-2.5\ ^{+1.4}_{-1.6}$ +/- 0.3)%	-5.8% < y' < 1.0%
x'	(0 +/- 1.5 +/- 0.2)%	| x' | < 2.9%
$(1/2)x'^2$		< 0.041%

Results



Limit when CP violation is allowed

$$R_M \to R_M (1 \pm A_M) \quad \text{(analogous to } \varepsilon\text{)}$$

$$R_D \to R_D (1 \pm A_D) \quad \text{(analogous to } \varepsilon'\text{)}$$

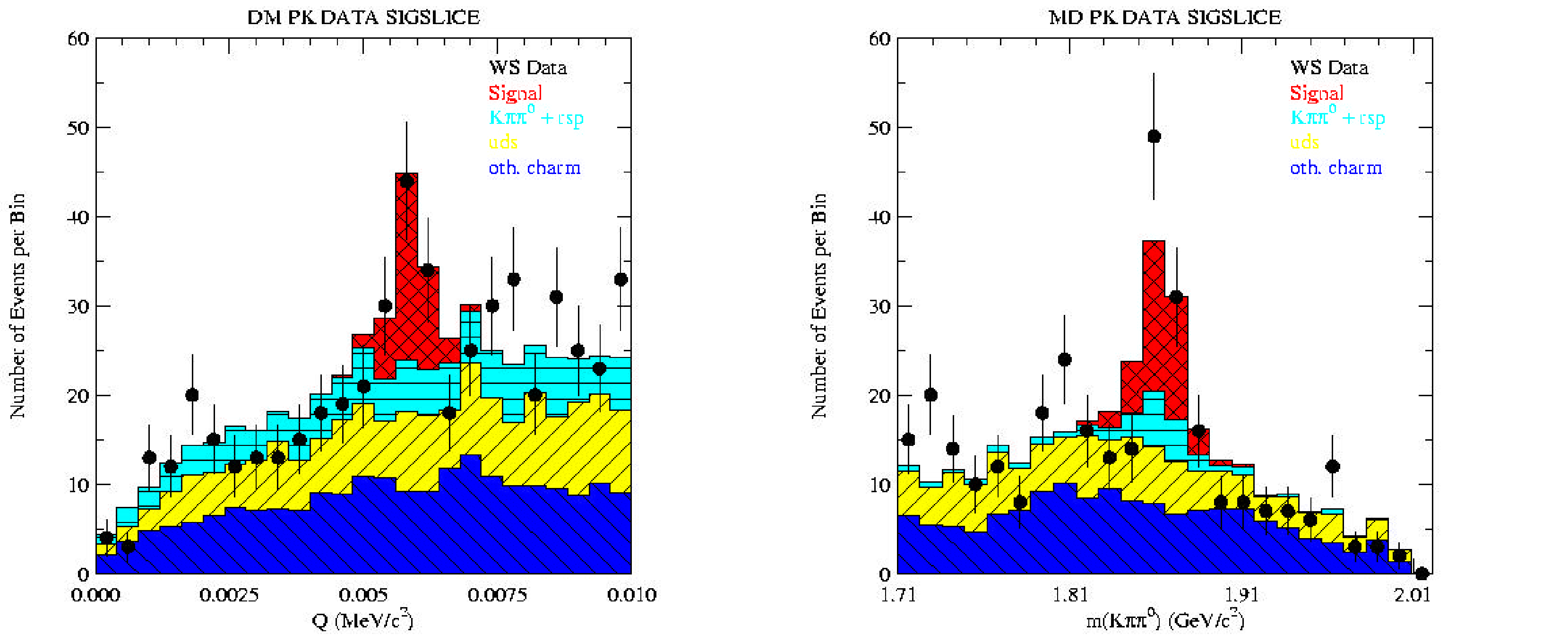
$$\delta \to \delta(1 \pm \phi) \quad \text{(analogous to } \sin 2\beta\text{)}$$

Parameter	Best Fit
A_M	$0.23^{+0.63}_{-0.80} \pm 0.01$
A_D	$-0.01^{+0.16}_{-0.17} \pm 0.01$
$\sin \phi$	$0.00 \pm 0.60 \pm 0.01$

Limit $-36\% < A_D < 30\%$ (95% C.L.)

Limit when CP violation is not allowed

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

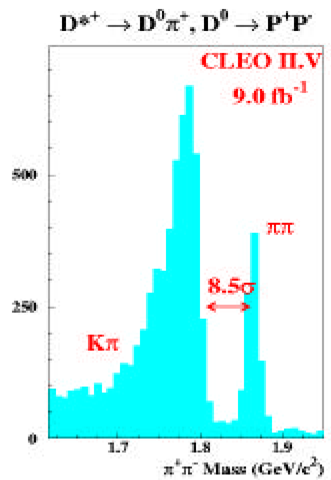


$$N_{WS} = 39^{+10}_{-9} \text{ (from fit)} \pm 7 \text{ (sys)}$$

$$N_{RS} = 9045$$

D Mixing Prospects

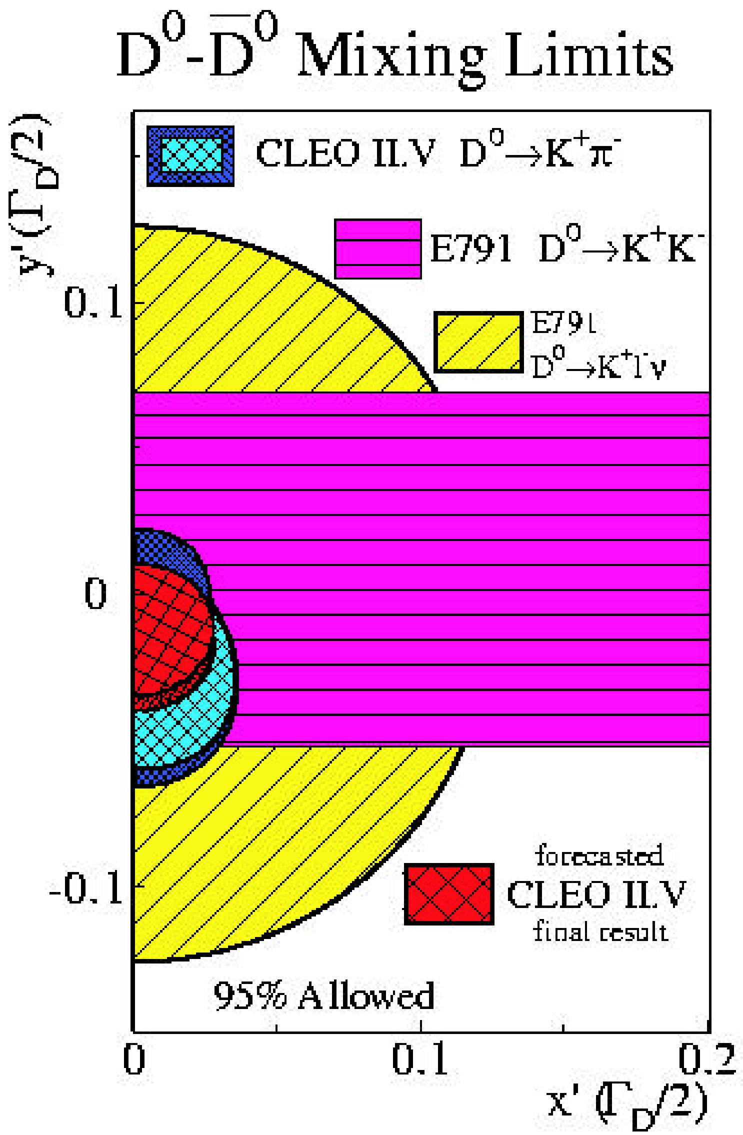
- CP Eigenstates (e.g D^0 -> KK, $\pi\pi$) lifetime analysis probes y= $\Delta\Gamma/2\Gamma$ directly.



p^+p^-

Expect σ_y ~ 1.8% (stat. + sys.)

- Semileptonic Decays D^0 -> $K^{*+}l\nu$
No DCSD, so R_D = 0 and R = R_M
Estimate sensitivity R_M < 0.15%

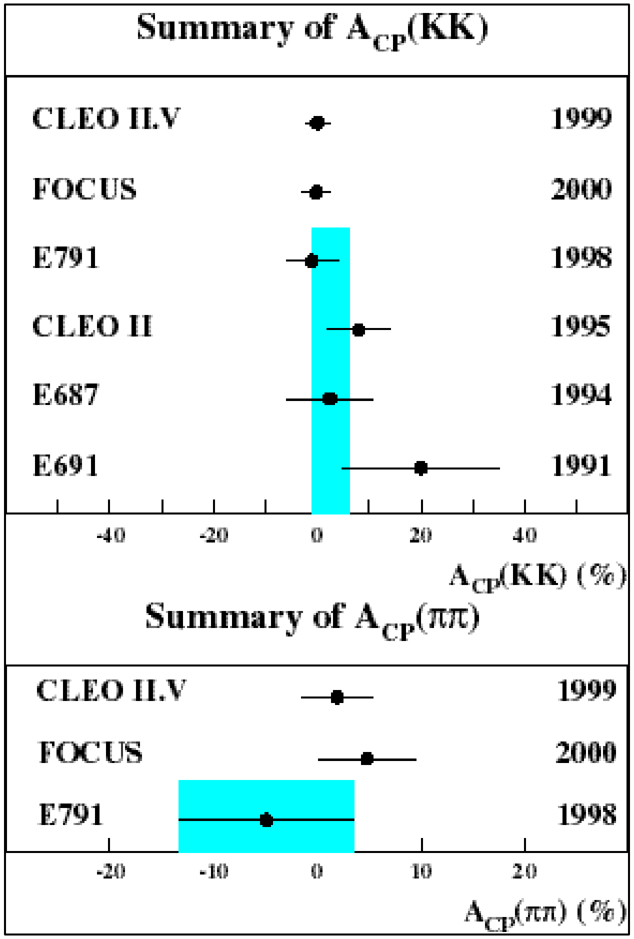


Search for CP Violation Using D^0 -> KK, $\pi\pi$

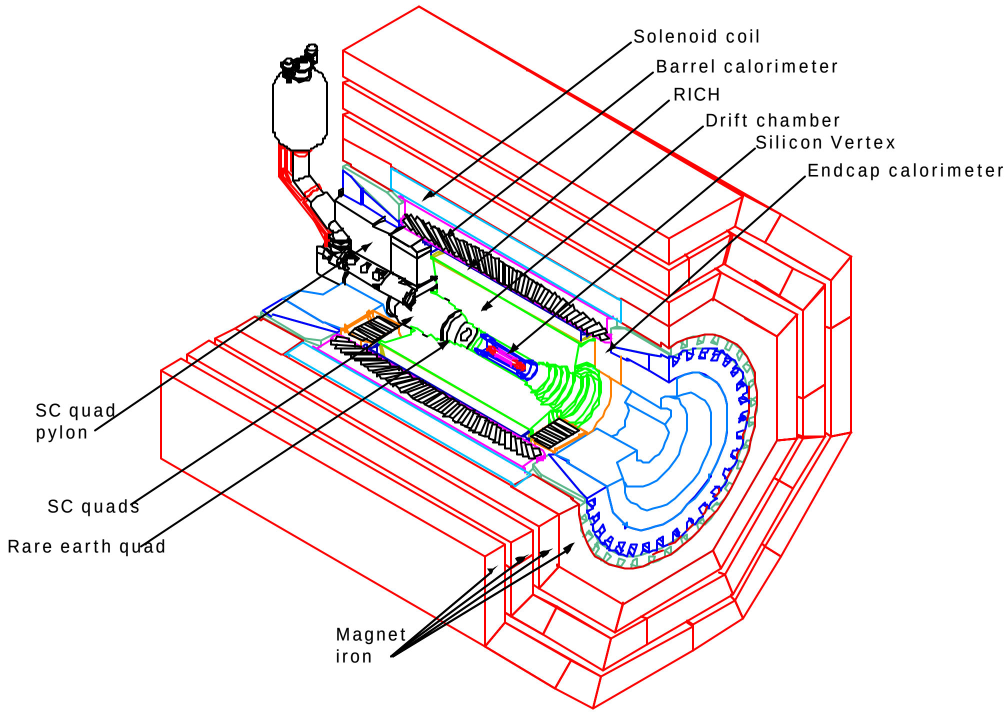
$$A_{CP}(f) = \frac{N(D^0 \to f) - N(\overline{D}^0 \to f)}{N(D^0 \to f) + N(\overline{D}^0 \to f)}$$

$$A_{CP}(KK) = (0.04 \pm 2.18(stat) \pm 0.84(sys))\%$$

$$A_{CP}(pp) = (1.94 \pm 3.22(stat) \pm 0.84(sys))\%$$

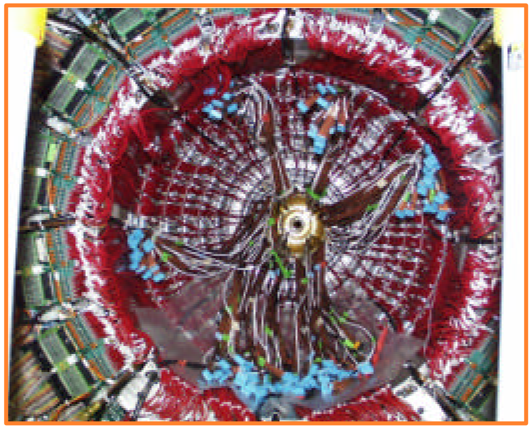


CLEO III

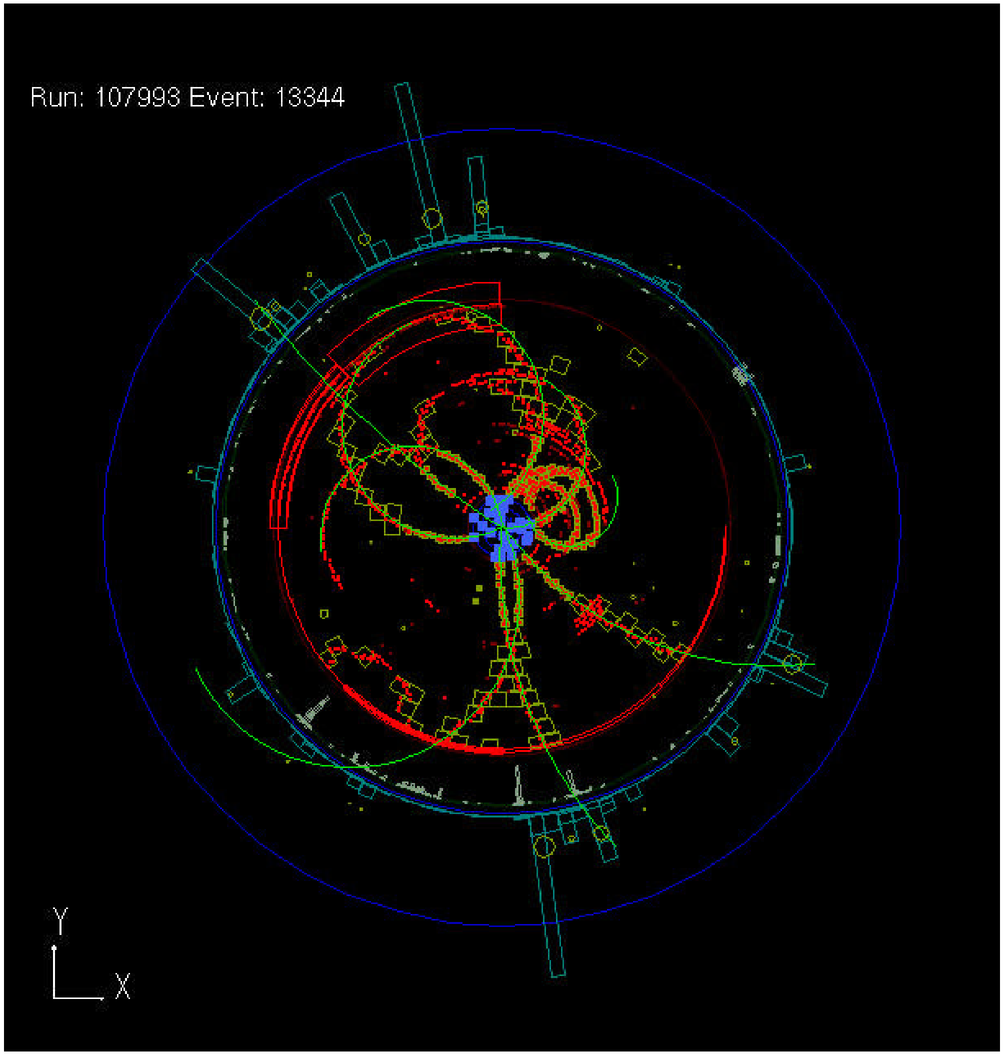


1999

2000

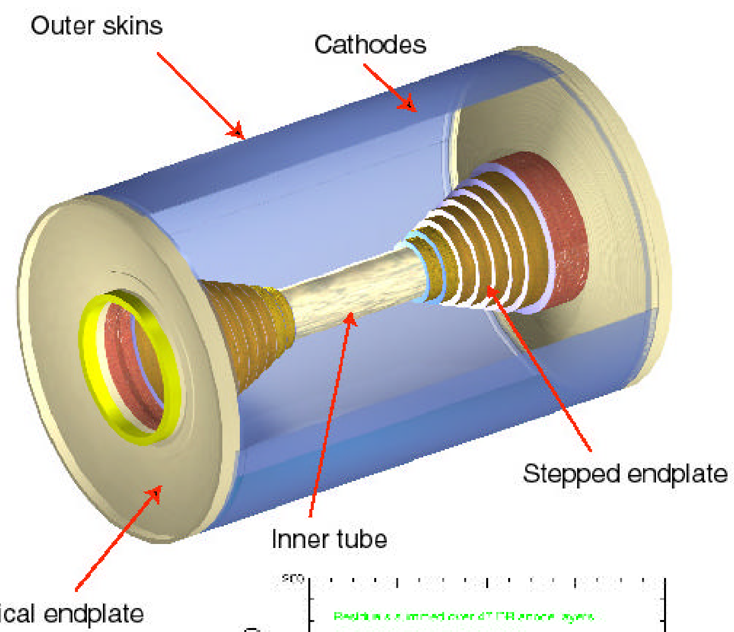


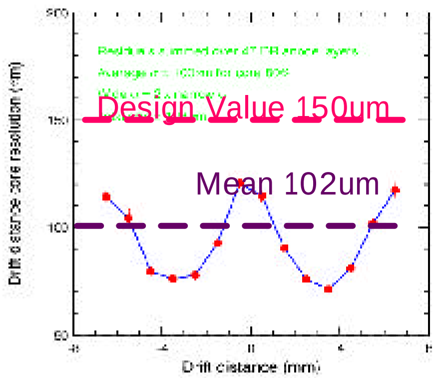
Hadronic Event

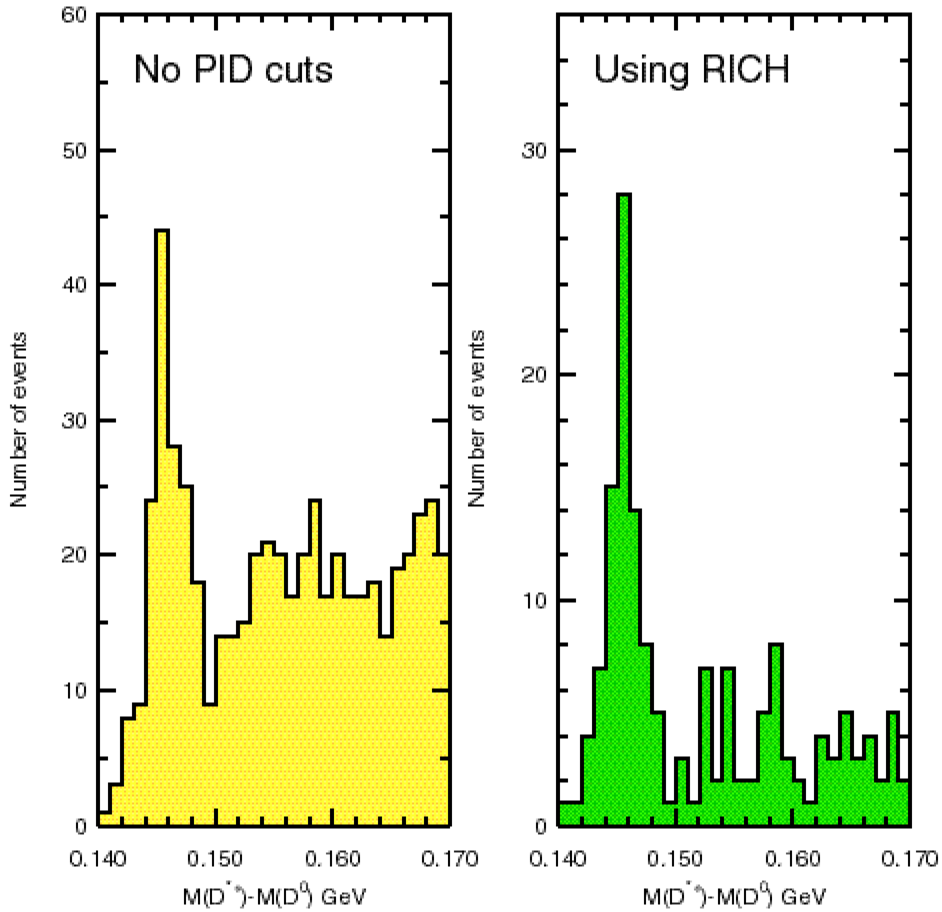


CLEO III Performance

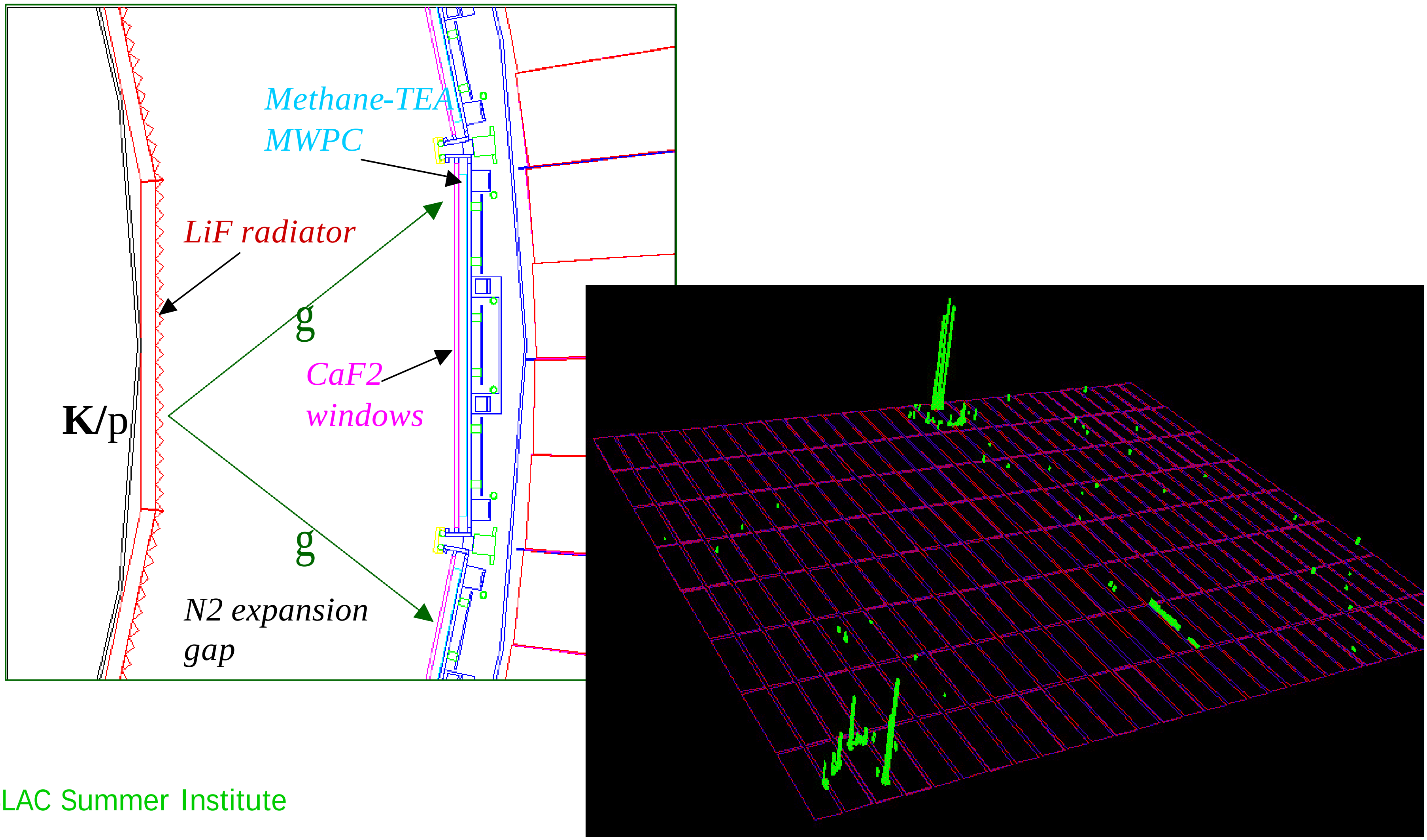
CLEO III Drift Chamber







RICH Principle

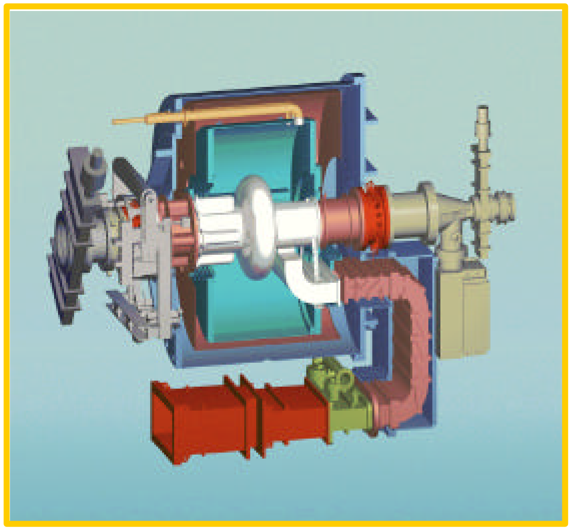


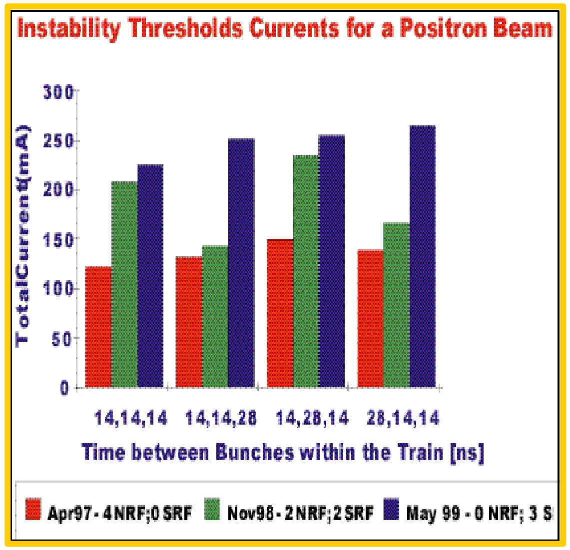
We are no longer alone...

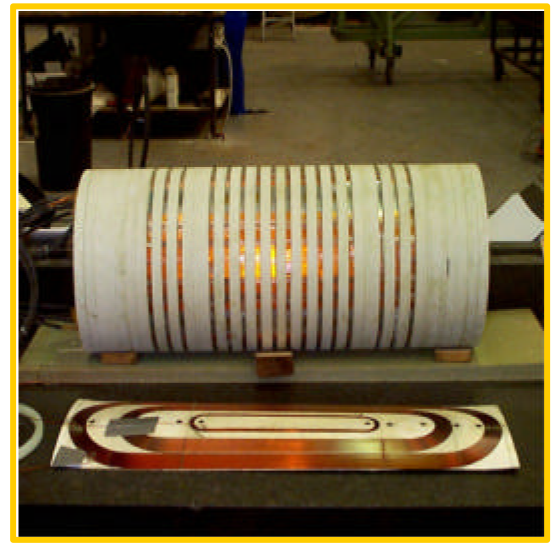
PEP II	CESR	
15 fb^{-1}	2 fb^{-1}	Int. L
2.3×10^{33} cm^{-2} s^{-1}	0.6×10 10^{33} cm^{-2} s^{-1}	Inst. L
	(1.7×10 10^{33} cm^{-2} s^{-1})	

BABAR	CLEO III	
20 μm	?	Si res.
125 μm	100 μm	aver. DR res.
100 μm	75 μm	best DR res.
7.5 %	5.0 %	dE/dx, Bhabha
7.2 MeV	5.4 MeV	π^0 res.
works	works	PID
70 Hz	70 Hz	Events to tape
1%	1%	DAQ deadtime

CESR III







Superconducting RF

- **More Power**
  - ⇨ **1 A beam current**
- **Less Impedance**
  - ⇨ **4 RF cells vs. 20**
  - ⇨ **Reduced Instabilities**
- **Higher Gradient**
  - ⇨ **Shorter Bunches**

Superconducting Quads

- **Better focus**
  - ⇨ b*** from 18 to 13 mm**
- **Spring 2001**

Conclusions

- Hadronic B Decays still interesting
  - Extended Factorization tests
  - New Charmonium decay modes
  - Intriguing interference pattern in charged B decay
- Large V_{cb} from exclusive decays
- New results on rare B
  - First observation of B->$\phi\pi$, many new modes
  - New limit on B->$\pi^0\pi^0$
  - Limits on CP asymmetries
- Limits on D^0-D^0 mixing and CP violation
- CLEO III up and running