Measurement of V_{cb} and Charmless Hadronic B Decays at CLEO

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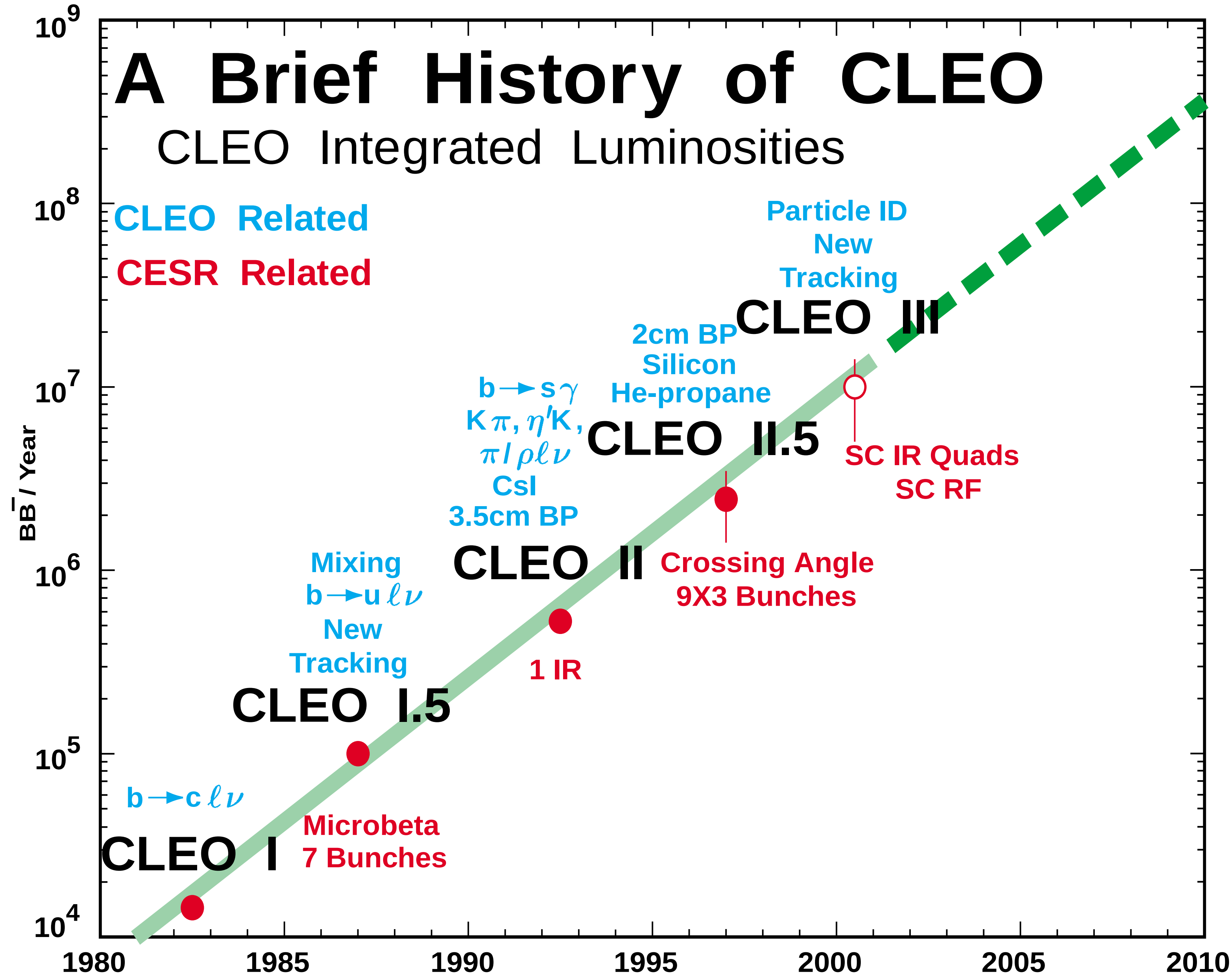
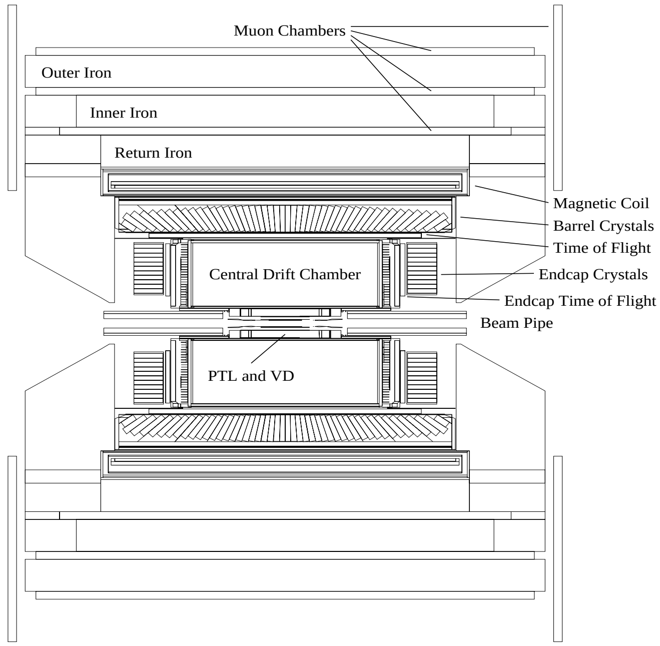
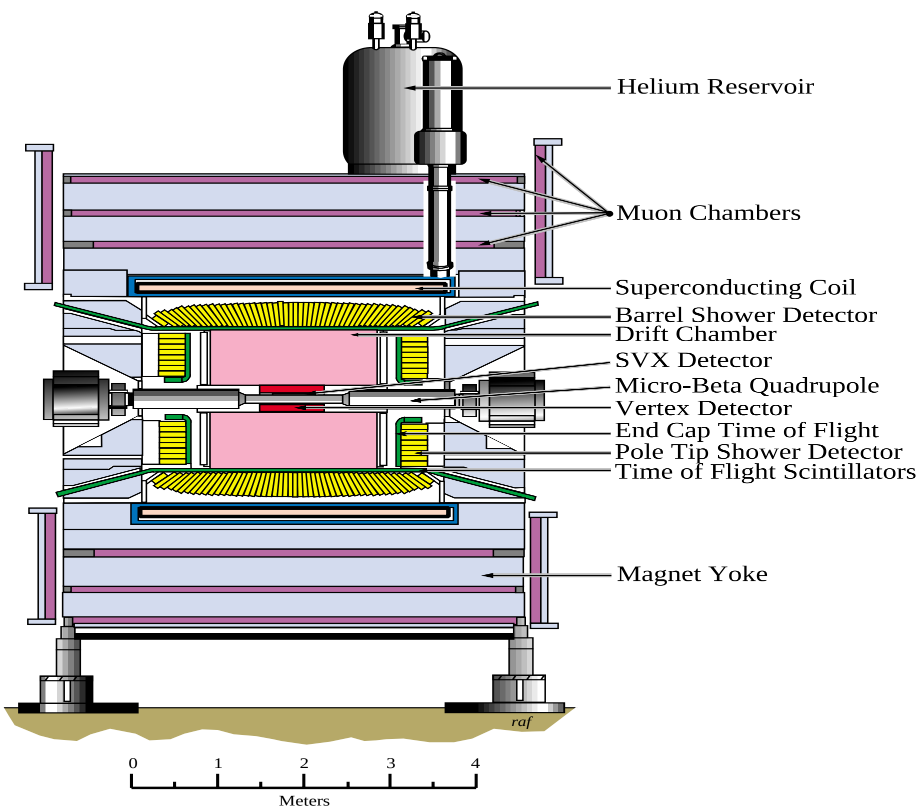
RADCOR' 2000

- **Introduction to CLEO**
- **Measurement of $|V_{cb}|$**
- **Charmless Hadronic B Decays**
- **CLEOIII Status**
- **Summary**

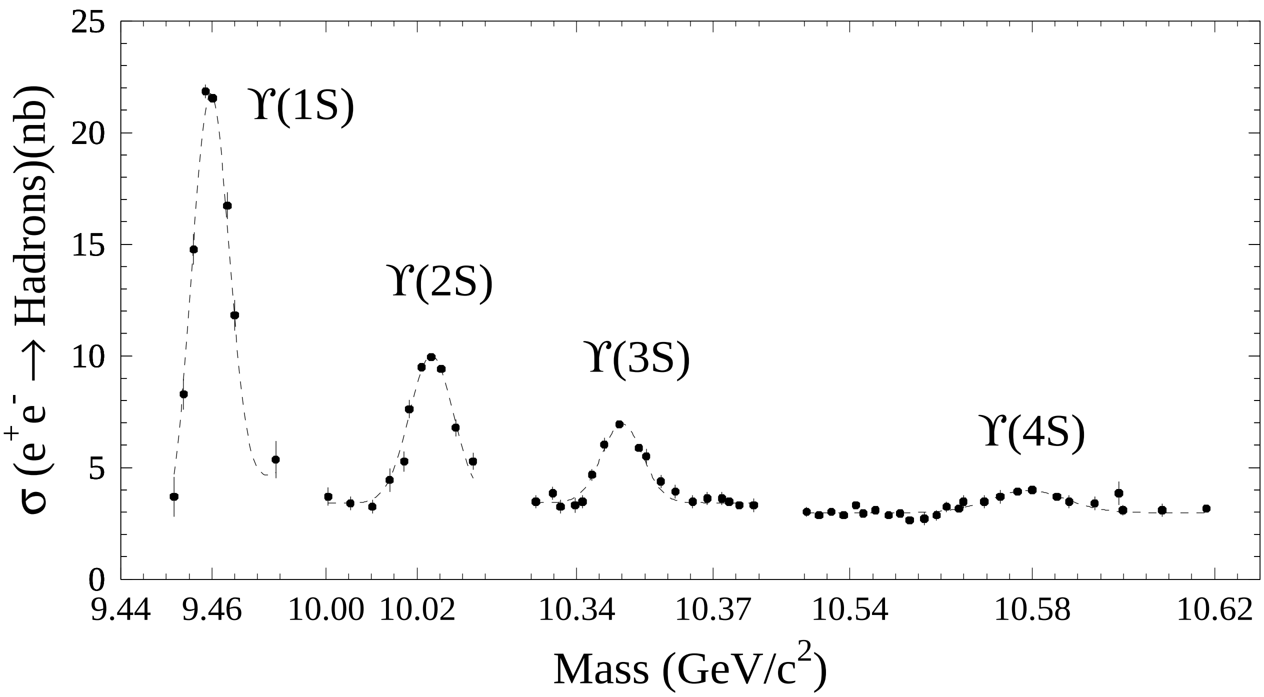

A Brief History of CLEO
CLEO Integrated Luminosities
CLEO Related
CESR Related
Particle ID
New
Tracking
CLEO III
2cm BP
Silicon
He-propane
CLEO II.5
SC IR Quads
SC RF
b→sγ
Kπ, η′K,
π / ρ ℓ ν
CsI
3.5cm BP
CLEO II
Crossing Angle
9X3 Bunches
Mixing
b→u ℓ ν
New
Tracking
1 IR
CLEO I.5
b→c ℓ ν
Microbeta
7 Bunches
CLEO I
BB̄ / Year
10^9
10^8
10^7
10^6
10^5
10^4
1980
1985
1990
1995
2000
2005
2010



CLEO II/II.V Detector



CLEO Data Set



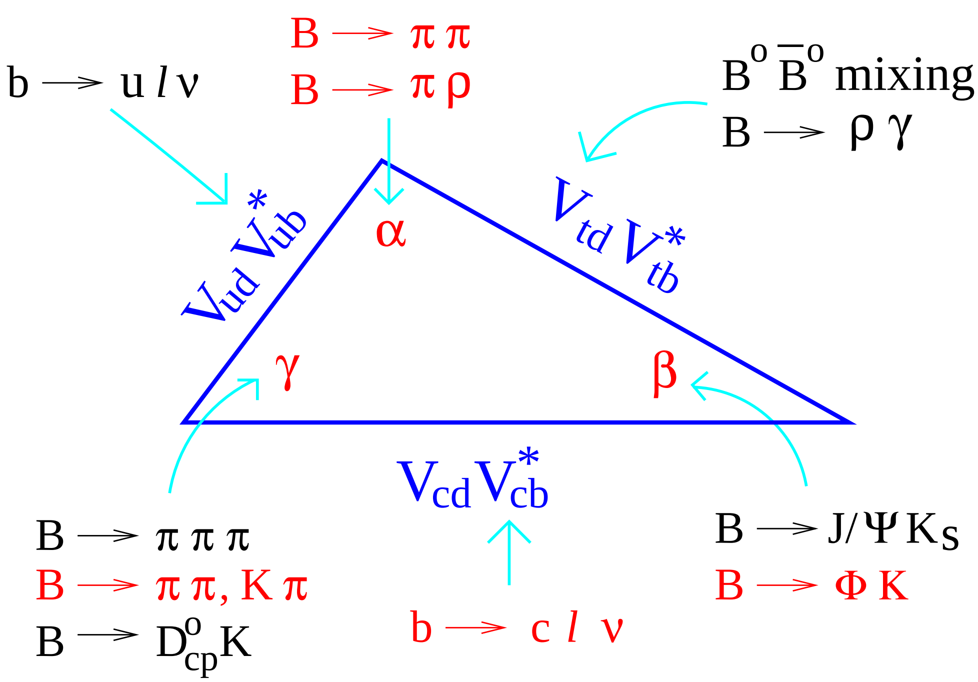
- Integrated Luminosity of 13.5 fb^{-1}
- 9.1 fb^{-1} on Υ(4S) : $\sim$ 9.7×10^6 $B\overline{B}$ events
- 4.4 fb^{-1} on continuum (60 MeV below the Υ(4S) resonance)
- 2/3 data taken in CLEO II.V configuration
- **CLEO analysis covers wide topics in B meson decay, esp. the measurements of the CKM matrix elements and CP violation.**

The CKM matrix and Unitary Triangle

- The CKM matrix
  The CKM matrix must be unitary in the Standard Model

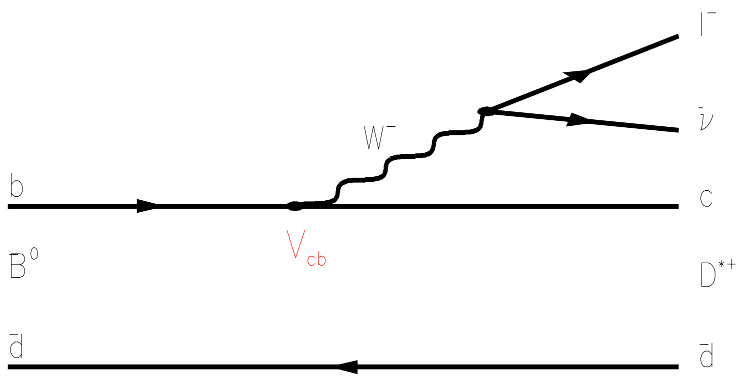
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$
$$V_{ub}V_{us}^* + V_{cb}V_{cs}^* + V_{tb}V_{ts}^* = 0$$
$$V_{us}V_{ud}^* + V_{cs}V_{cd}^* + V_{ts}V_{td}^* = 0$$

- The Unitary Triangles



- **Below I will focus on the new CLEO results of the measurement of $|V_{cb}|$ and charmless hadronic B decays**

$|V_{cb}|$ from $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$



The partial width of $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$ is proportional to $|V_{cb}|^2$:

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

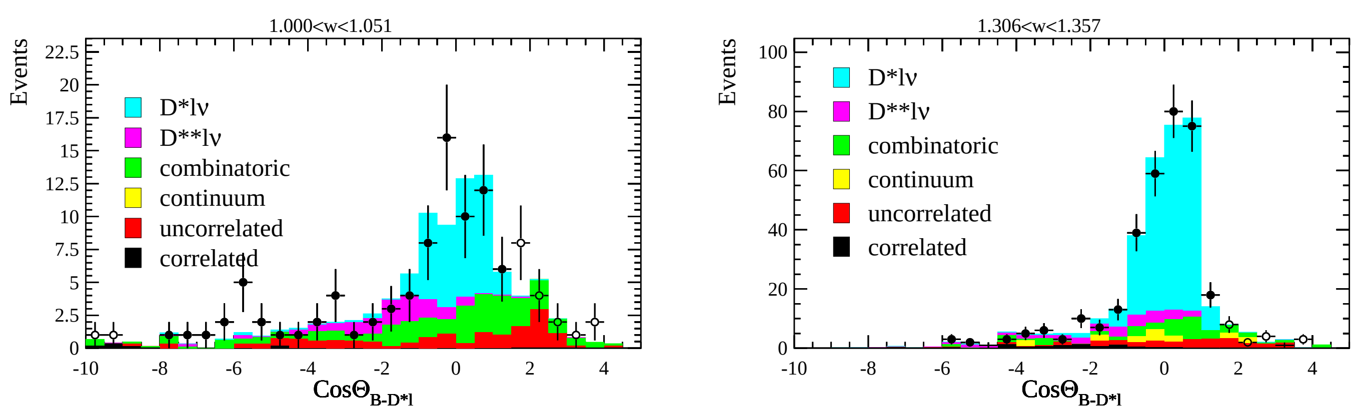
- $w = v_B \cdot v_{D^*}$, the relativistic γ of D^* in the B rest frame.
- $\mathcal{G}(w)$ contains kinematic factors and is *known*
- $\mathcal{F}(w)$ is the form factor describing $B \to D^*$ transition.

At zero recoil of D^* (i.e. $w = 1$), $\frac{d\Gamma}{dw} \propto (\mathcal{F}(1)|V_{cb}|)^2$, $\mathcal{F}(1)$ can be calculated by theory like HQET(Heavy Quark Effective Theory).

Analysis Technique

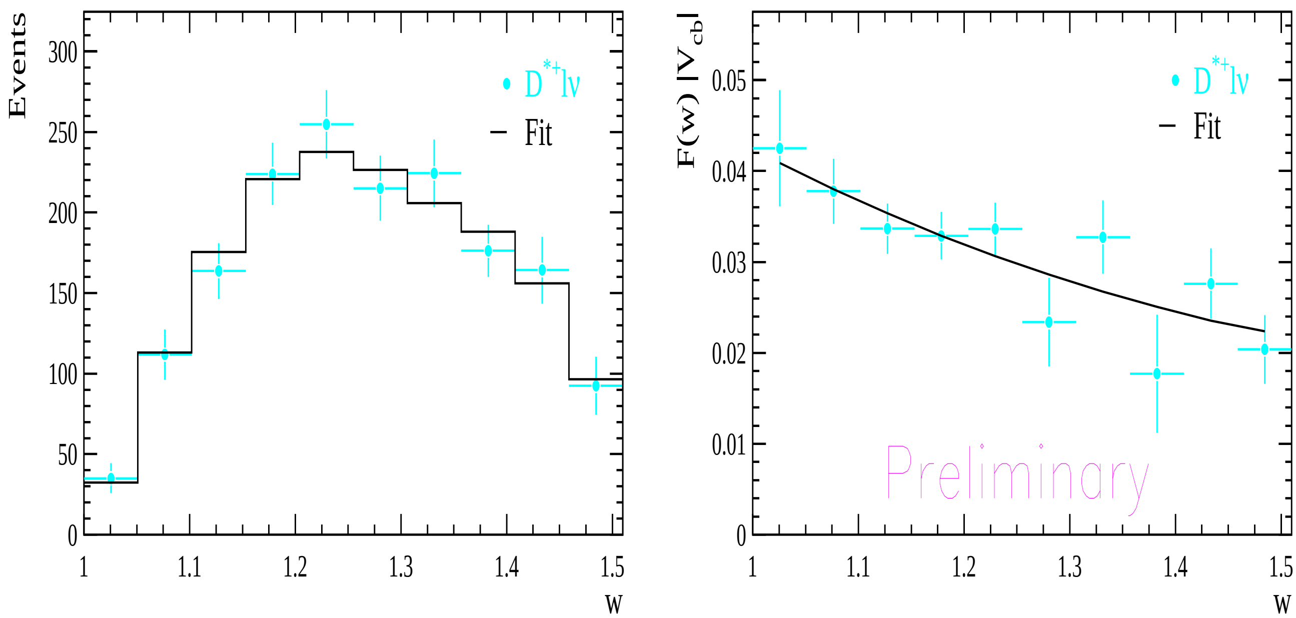
- The technique is to measure $d\Gamma/dw$ and extrapolate to $w = 1$ to extract $\mathcal{F}(1)|V_{cb}|$. For $D^*\ell\nu$, w runs from 1 to 1.5. We divide it into ten bins.
  (use CLEO-II sample $\sim 3 \times 10^6$ $B\overline{B}$ events)
- Event full reconstruction : $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$, $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$
- The $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$ yield in each w bin is extracted from a likelihood fit to the $\cos\theta_{B-D^*\ell}$ distribution [a], which can well distinguish between $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$ and $\bar{B}^0 \to D^{*+}X\ell^-\bar{\nu}$ ($\bar{B}^0 \to D^{**+}\ell^-\bar{\nu}$ and $\bar{B}^0 \to D^{*+}\pi\ell^-\bar{\nu}$, non-zero missing mass)

Representative fit plots



[a] the angle between the $D^*\ell$ combination and B

Fitting $d\Gamma/dw$



- We then do a χ^2 fit on the overall w distribution taking into account backgrounds, reconstruction efficiency and the w resolution($\sigma_w \sim 0.03$).

- We use the dispersion relations[a] to constrain the shapes of the form factor $\mathcal{F}(w)$ and fit for $\mathcal{F}(1)|V_{cb}|$ and a "slope", ρ^2 $(w = 1)$.

[a] Caprini, Lellouch and Neubert (NP**B**530, 153)

Systematic Errors

Source	$\|V_{cb}\|\mathcal{F}(1)(\%)$	$\rho^2(\%)$	$\Gamma(B \to D^*\ell\nu)(\%)$
Slow π finding	3.1	3.7	2.9
Combinatoric Bkgd	1.4	1.8	1.2
Lepton ID	1.1	0.0	2.1
K, π &ℓ finding	1.0	0.0	1.9
Number of $B\bar{B}$ events	0.9	0.0	1.8
Uncorrelated Bkgd	0.7	0.9	0.7
Correlated Bkgd	0.4	0.3	0.5
B momentum & mass	0.3	0.5	0.4
$D^*X\ell\nu$ model	0.2	1.9	1.9
Subtotal	3.8	4.7	5.0
$R_1(1)$ and $R_2(1)$	1.4	12.0	1.8
B($D \to K\pi$)	1.2	0.0	2.3
τ_B	1.0	0.0	2.1
B($D^* \to D\pi$)	0.4	0.0	0.7
Subtotal	2.2	12.0	3.7
Total	**4.4**	**13**	**6.2**

RESULTS

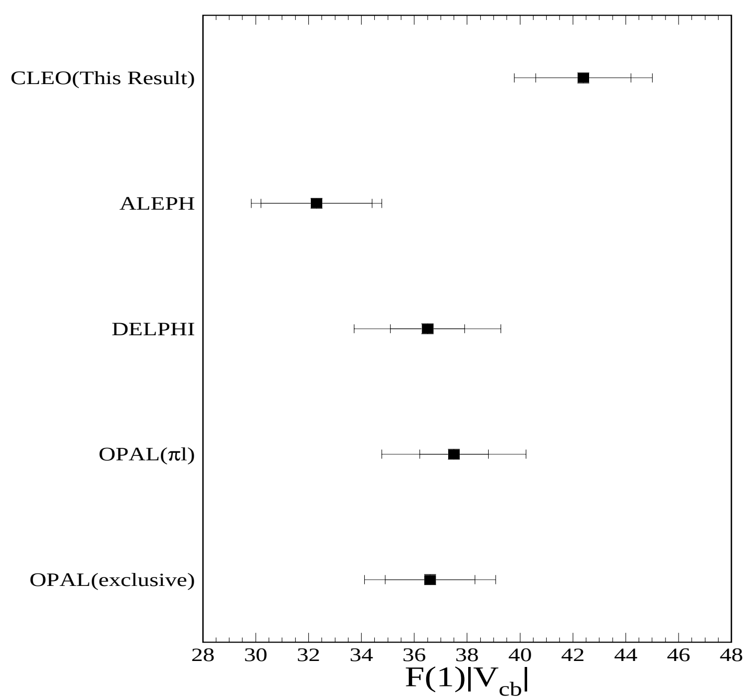
We find

$$\mathcal{F}(1)|V_{cb}| = (42.4 \pm 1.8 \pm 1.9) \times 10^{-3}$$
$$\mathcal{B}(\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}) = (5.66 \pm 0.29 \pm 0.33)\%$$

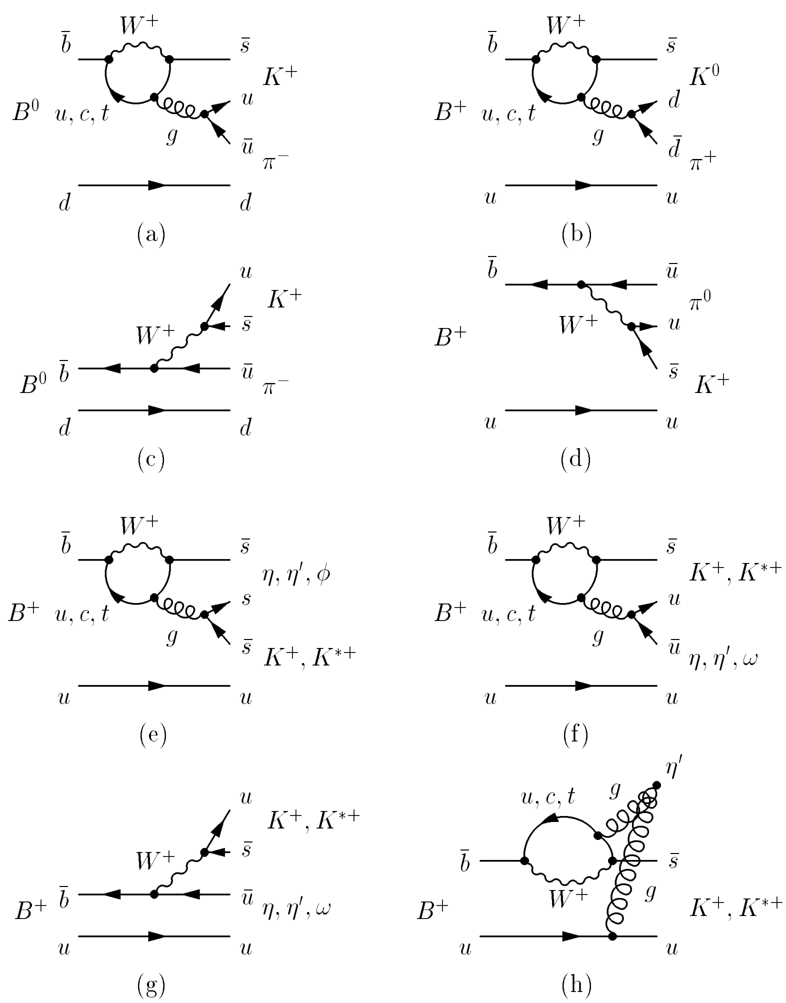
Using $\mathcal{F}(1) = 0.913 \pm 0.042$, we calculate

$$|V_{cb}| = (46.4 \pm 2.0 \pm 2.1 \pm 2.1) \times 10^{-3}$$

- This result is comparable to LEP's but somewhat larger
- A measurement using $D^{*0}\ell\nu$ will come soon. Combining these two channels will give the best single measurement of $|V_{cb}|$ using the exclusive technique.



Charmless Hadronic Two-Body B Decays



Two main types of diagrams:

- $b \to u$ spectator (tree) diagrams (suppressed by V_{ub})
- $b \to s$ penguin diagrams (suppressed by loops)
- Usually, there is more than one contribution to one decay

Analysis Technique

Signal: $e^+e^- \to \Upsilon(4S) \to B\overline{B}$ ($\sigma \sim 1$ nb)

Background: $e^+e^- \to q\overline{q}$, $q = u, d, s, c$ ($\sigma \sim 3$ nb)

Initial selection constraints:

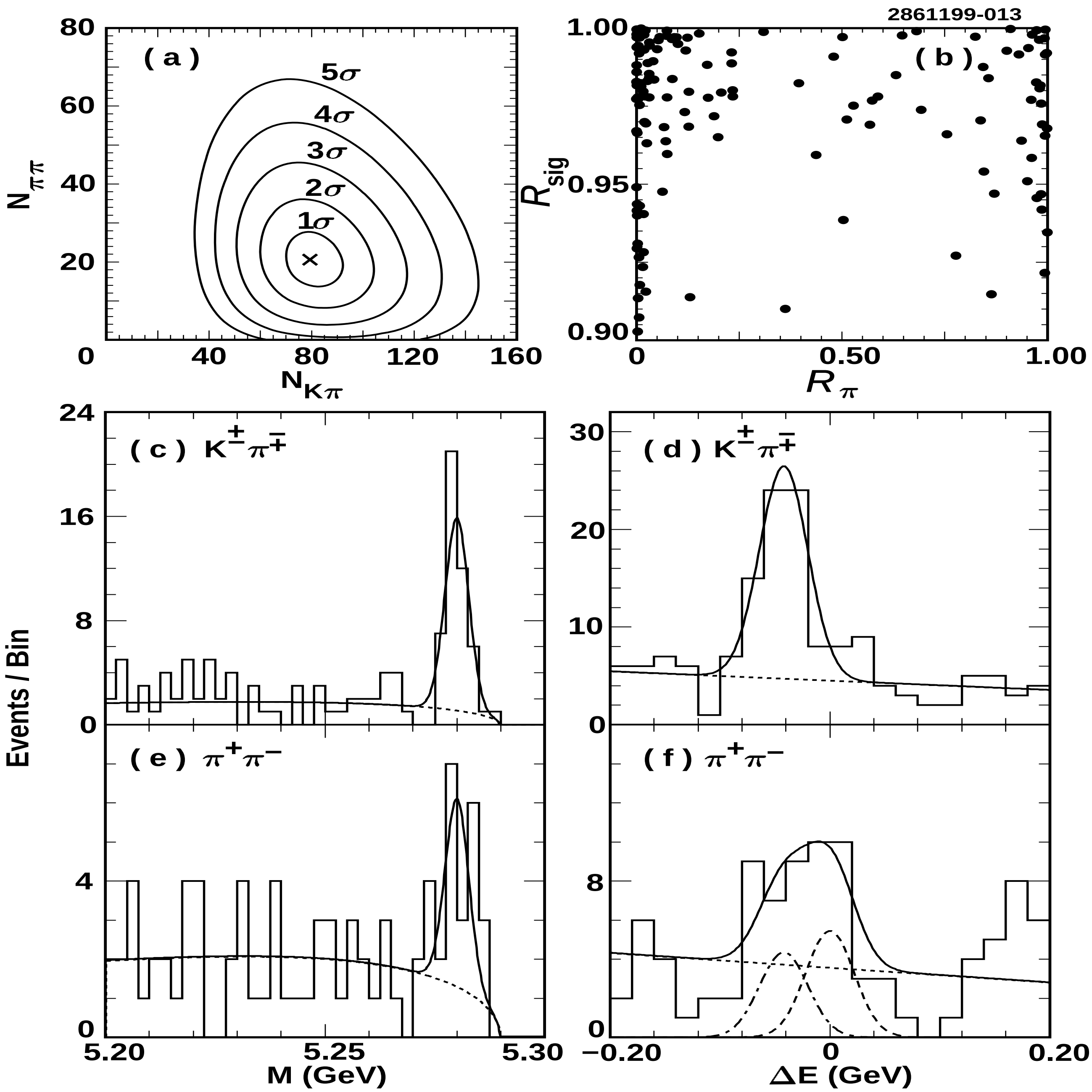
- $m_B \equiv \sqrt{E_{\rm beam}^2 - |\sum_i \mathbf{p}_i|^2}$ ($\sigma_{m_B} \approx 2.5$ MeV)
- $\Delta E \equiv \sum_i E_i - E_{\rm beam}$ ($\sigma_{\Delta E} \approx$ 20-30 MeV)
- Continuum suppression via event shape (continuum "jetty", $B\overline{B}$ "spherical")

Yields determined from unbinned maximum likelihood fits.

Variables used to distinguish *signal* from *background*:

- Mass and energy of B candidates: m_B and ΔE.
- Fisher discriminant - *linear combination of 11 shape variables.*
- B candidate flight direction.
- Resonance masses and helicity angle for VP decays.
- dE/dx and ΔE for particle ID.
  - At high p, weak separation of $K^\pm$ and $\pi^\pm \Rightarrow$ Simultaneously fit for both components (*e.g.* $B \to K^\pm\pi^\mp/\pi^\pm\pi^\mp$).

Illustration of Fit Results for $B \to K^{\pm}\pi^{\mp}$,$\pi^{\pm}\pi^{\mp}$



$B \to K\pi,\ \pi\pi$

Mode	ϵ(%)	Yield	Signif.	$\mathcal{B}(10^{-6})$
$K^\pm\pi^\mp$	48	$80.2^{+11.8}_{-11.0}$	11.7σ	$17.2^{+2.5}_{-2.4}\pm1.2$
$K^0\pi^\pm$	14	$25.2^{+6.4}_{-5.6}$	7.6σ	$18.2^{+4.6}_{-4.0}\pm1.6$
$K^\pm\pi^0$	38	$42.1^{+10.9}_{-9.9}$	6.1σ	$11.6^{+3.0+1.4}_{-2.7-1.3}$
$K^0\pi^0$	11	$16.1^{+5.9}_{-5.0}$	4.9σ	$14.6^{+5.9+2.4}_{-5.1-3.3}$
$\pi^\pm\pi^\mp$	48	$20.0^{+7.6}_{-6.5}$	4.2σ	$4.3^{+1.6}_{-1.4}\pm0.5$
$\pi^\pm\pi^0$	39	$21.3^{+9.7}_{-8.5}$	3.2σ	< 12.7
$\pi^0\pi^0$	29	$6.2^{+4.8}_{-3.7}$	2.0σ	< 5.7
$K^\pm K^\mp$	48	$0.7^{+3.4}_{-0.7}$	0.0σ	< 1.9
$K^\pm K^0$	14	$1.4^{+2.4}_{-1.3}$	1.1σ	< 5.1
$K^0\bar{K}^0$	5	0	0.0σ	< 17

(All upper limits at 90% C.L.)

- All four $K\pi$ modes are observed
  $\to$ bound on the angle γ of the unitary triangle.
- $B \to \pi^0\pi^0$ is a new result.
- Gluonic penguin contribution is large.

Modes with η' and η

Mode	Signif.	$\mathcal{B}$ (10^{-6})
$B^+ \to \eta' K^+$	16.8σ	$80^{+10}_{-9} \pm 7$
$B^0 \to \eta' K^0$	11.7σ	$89^{+18}_{-16} \pm 9$
$B^+ \to \eta K^{*+}$	4.8σ	$26.4^{+9.6}_{-8.2} \pm 3.3$
$B^0 \to \eta K^{*0}$	5.1σ	$13.8^{+5.5}_{-4.6} \pm 1.6$

- No significant signals in other η' and η modes (we set upper limits instead)
- Confirmed large $\eta' K$ signal
- Intrinsic charm content of η' has been proposed

New CLEO results on $B \to \eta_c K$:

$$BR(B^0 \to \eta_c K^0) = (1.09^{+0.55}_{-0.42} \pm 0.12 \pm 0.31) \times 10^{-3}$$

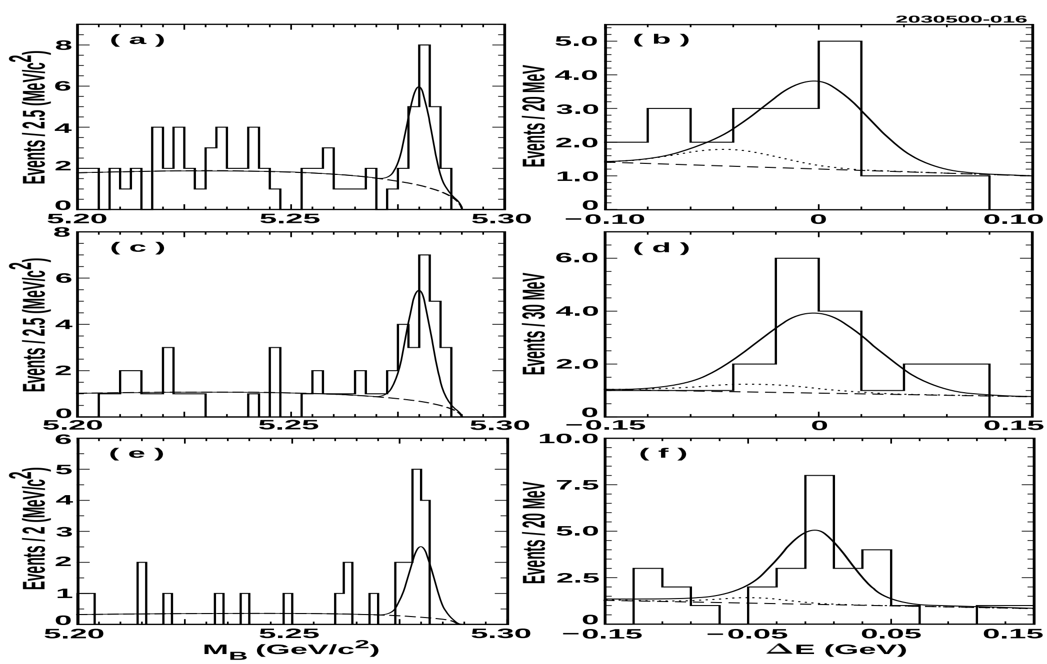
$$BR(B^+ \to \eta_c K^+) = (0.69^{+0.26}_{-0.21} \pm 0.08 \pm 0.20) \times 10^{-3}$$

No enhancement has been seen compared to the $B \to J/\psi K$ channel

$B \to PV$ Modes

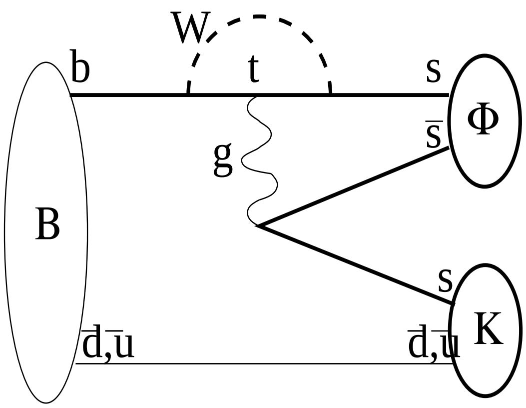
Mode	Yield	Signif.	$\mathcal{B}$ (10^{-6})
$B^- \to \pi^- \rho^0$	$29.8^{+9.3}_{-9.6}$	5.4σ	$10.4^{+3.3}_{-3.4} \pm 2.1$
$B^- \to \pi^- \omega$	$28.5^{+8.2}_{-7.3}$	6.2σ	$11.3^{+3.3}_{-2.9} \pm 1.4$
$B^0 \to \pi^\pm \rho^\mp$	$31.0^{+0.4}_{8.3}$	5.6σ	$27.6^{+8.4}_{-7.4} \pm 4.2$

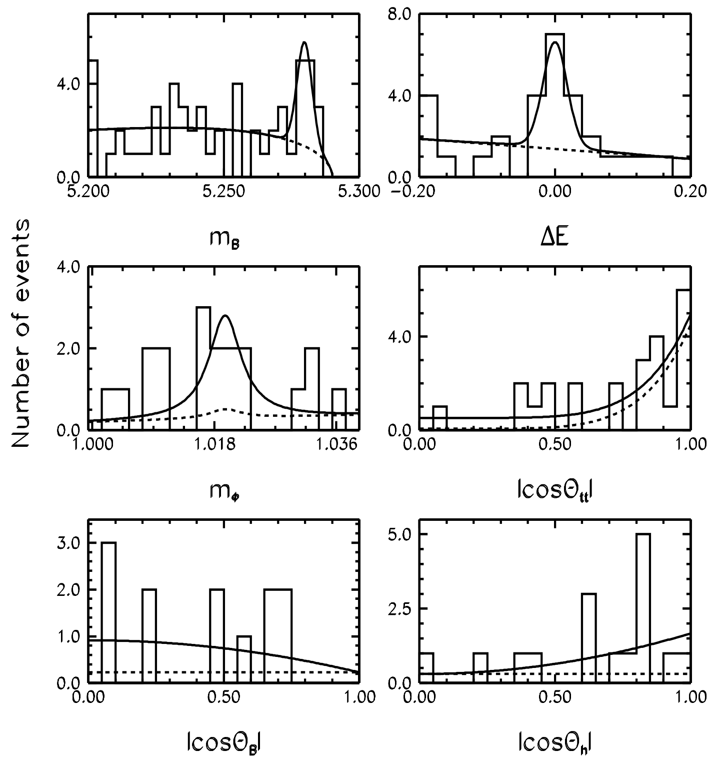
- First observation of the above ΔS=0 decay modes.
- We see no significant yields in any of the ΔS=1 transitions, which indicates that gluonic penguin decays play less of a role in $B \to PV$ decays than in $B \to PP$ decays. (as expected in factorization based models)



$B \to \phi K$ - Preliminary

Pure gluonic penguin, simple final state, sensitive to $\sin 2\beta$





Combine the $B^- \to \phi K^-$ and $BR(B^0 \to \phi K^0)$ measurements we observe

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

CP Asymmetry Measurements

Direct CP asymmetry can result from interference of two amplitudes with different strong and weak phases.

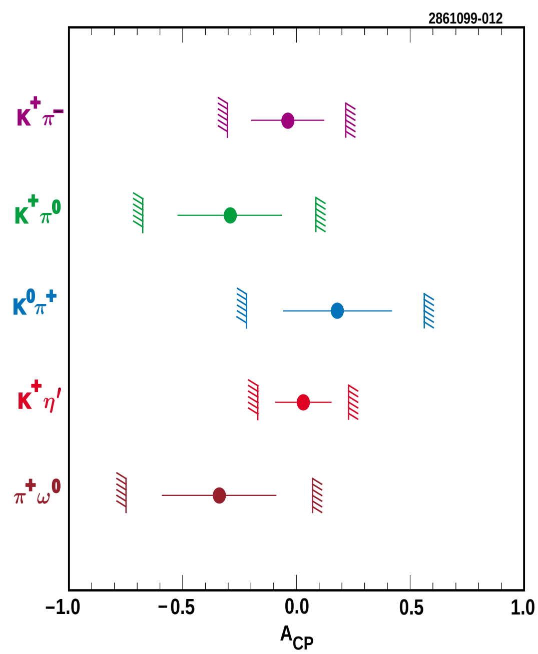
- Definition

$$\mathcal{A}_{CP} \equiv \frac{\mathcal{B}(\bar{B} \to f) - \mathcal{B}(B \to \bar{f})}{\mathcal{B}(\bar{B} \to f) + \mathcal{B}(B \to \bar{f})}$$

- Parent B flavor self-tagged by high-p charged particle.
- $\mathcal{A}_{\mathcal{CP}}$ included as free parameter in ML fits.

Mode	**Yield**	$\mathcal{A}_{\mathcal{CP}}$
$K^{\pm}\pi^{\mp}$	$80.2^{+11.8}_{-11.0}$	-0.04 ± 0.16
$K^{\pm}\pi^{0}$	$42.1^{+10.9}_{-9.9}$	-0.29 ± 0.23
$K^{0}\pi^{\pm}$	$25.2^{+6.4}_{-5.6}$	$+0.18 \pm 0.24$
$K^{\pm}\eta'$	100^{+13}_{-12}	$+0.03 \pm 0.12$
$\omega\pi^{\pm}$	$28.5^{+8.2}_{-7.3}$	-0.34 ± 0.25

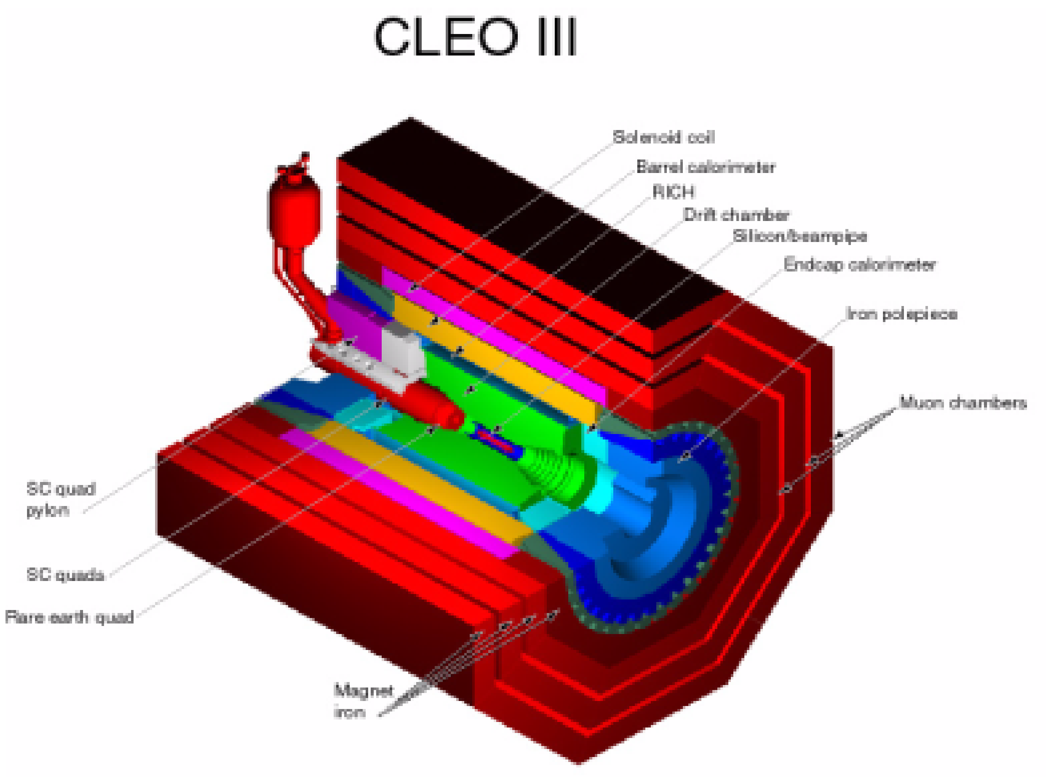
90% C.L. intervals



- No $\mathcal{A}_{\mathcal{CP}}$ observed, but allowed range significantly reduced.
- All measurements are statistics-limited.

CLEO III Status

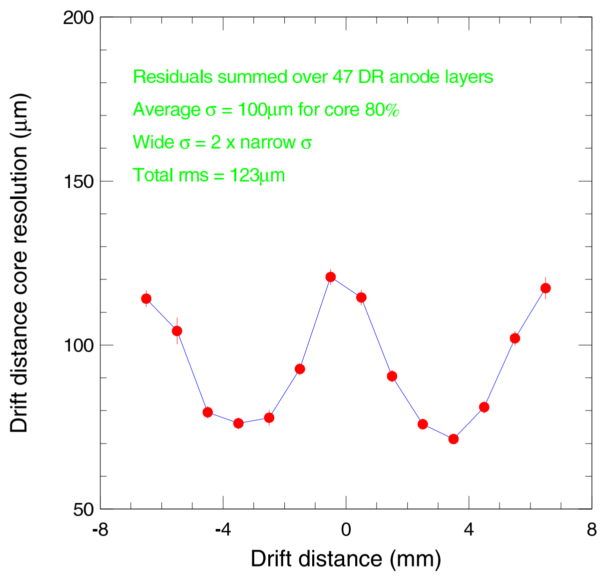
CLEO III had a successful engineering run this spring and began data taking in mid-july

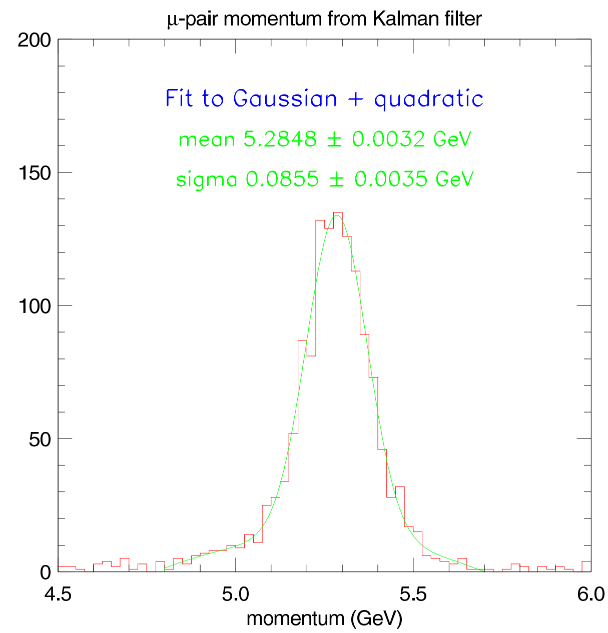


CESR upgrades	New detectors in CLEO
$I_{perbeam}$= up to 500 mA	4-layer Silicon vertex detector
L$\sim 1.6 - 2.2 \times 10^{33} cm^{-2} s^{-1}$	Drift Chamber
20-30 fb^{-1}/year	Ring Imaging CHernkov (RICH)

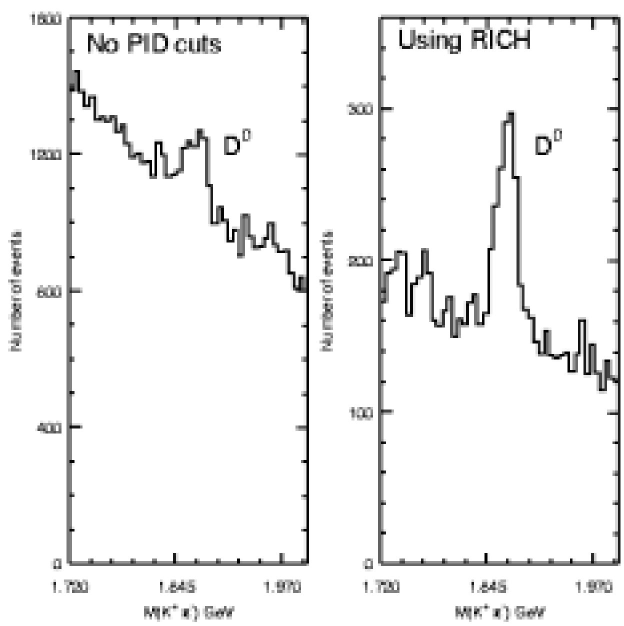
CLEO III Status

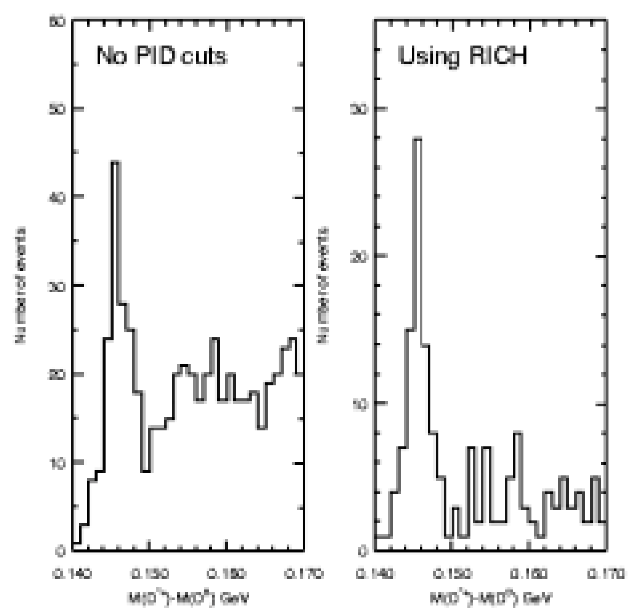
Drift Chamber has shown very good momentum and tracking resolution





RICH is very effective in PID





Conclusion

- CLEO continues to mine our data for new results, very wide and deep program
- Good measurement of $|V_{cb}|$
- Comprehensive measurement on exclusive charmless hadronic B decays
  - Due to statistics limit and theoretical uncertainties, the measurements can't be precisely converted into CKM elements. But very useful to test various phenomenological models.
  - Data indicate existence of many contributing and interfering diagrams.
    The gluonic penguin contribution is large.
- Many other physics results.
- CLEO III detector works very well, we are exploring the best place to run the beautiful detector.