Measurement of $|V_{cb}|$ with $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$ at CLEO

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

The partial width is proportional to $|V_{cb}|^2$:

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

$$w = v_B \cdot v_{D^*} = \frac{m_B^2 + m_{D^*}^2 - q^2}{2m_B m_{D^*}}$$

For $D^*\ell\nu$, w runs from 1 to 1.5.

$$\mathcal{G}(w) = m_{D^*}^3(m_B - m_{D^*})^2\sqrt{w^2-1}(w+1)^2\left[1 + \frac{4w}{w+1}\frac{1-2wr+r^2}{(1-r)^2}\right]$$

with $r = m_{D^*}/m_B$

- $\mathcal{G}(w)$ contains kinematic factors and is *known*
- $\mathcal{F}(w)$ is the form factor describing $B \to D^*$ transition
  - HQET relations simplify the most general form factor
  - absolutely normalized at zero recoil ($w = 1$)
  - As $m_Q \to \infty$, $\mathcal{F}(1) \to 1$; corrections of order $1/m_Q^2$

The plan is to measure $d\Gamma/dw$ and extrapolate to $w = 1$ to extract $\mathcal{F}(1)|V_{cb}|$. We divide the data into ten bins of w and measure the $D^{*+}\ell\nu$ yield.

$D^*\ell\nu$ Form Factor

The form factor is parameterized in HQET as

$$\mathcal{F}(w) = h_{A_1}(w)\sqrt{\frac{\tilde{H}_0^2 + \tilde{H}_+^2 + \tilde{H}_-^2}{1 + 4\frac{w}{w+1}\frac{1-2wr+r^2}{(1-r)^2}}}.$$

Helicity Form Factors:

$$\begin{aligned}\tilde{H}_0(w) &= 1 + \frac{w-1}{1-r}(1 - R_2(w)) \\ \tilde{H}_\pm(w) &= \frac{\sqrt{1-2wr+r^2}}{1-r}\left(1 \mp \sqrt{\frac{w-1}{w+1}}R_1(w)\right)\end{aligned}$$

Form Factor Ratios: (measured PRL **76**, 3898)

$$\begin{aligned}R_1(w) &= h_V(w)/h_{A_1}(w) &\approx 1.2 \\ R_2(w) &= (h_{A_3}(w) + r h_{A_2}(w))/h_{A_1}(w) &\approx 0.7\end{aligned}$$

$h_{A_1}(w)$ may be expanded in a Taylor series around $w = 1$:

$$h_{A_1}(w) = h_{A_1}(1)(1 - \rho^2_{h_{A_1}}(w-1) + \ldots)$$

Alternatively dispersion relations may be used to constrain the functional form of $h_{A_1}(w)$. (PR**D56**,6895; NP**B530**,153)

HQET also provides a robust prediction for the normalization at $w = 1$: (PL**B264**,455; **338**,84; PR**D47**,2965; **51**,2217; **52**, 3149; PRL 76, 4124)

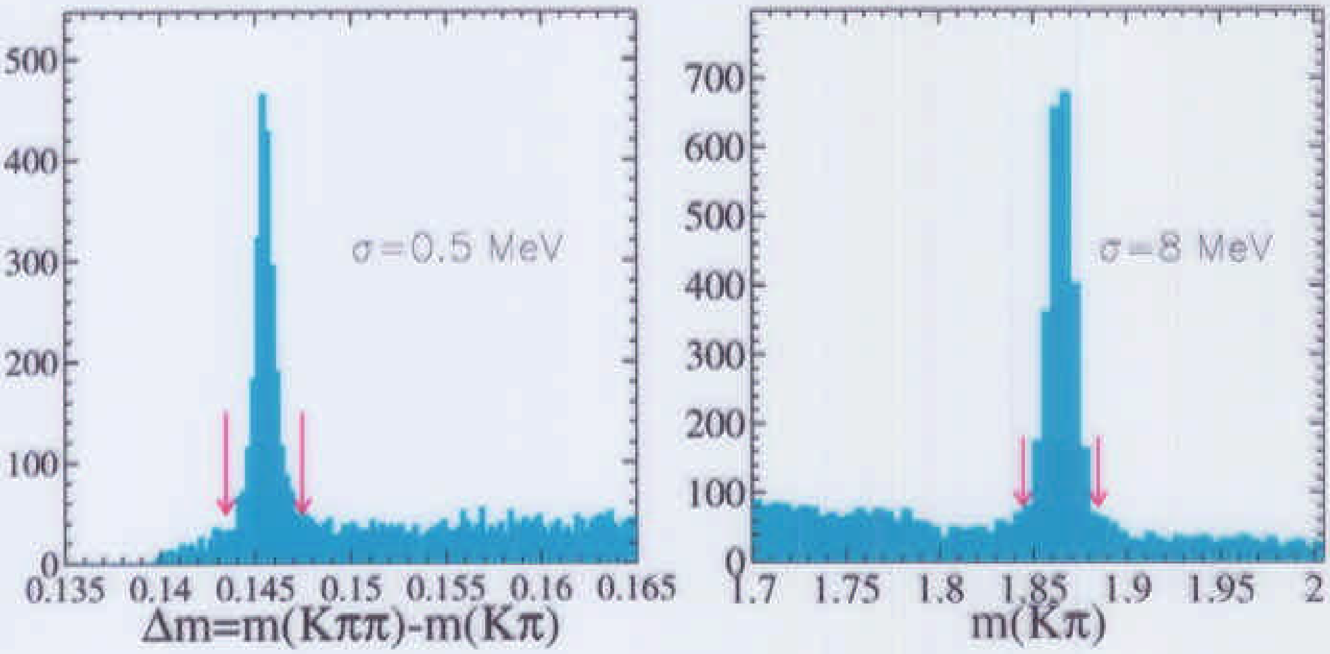
$$\mathcal{F}(1) = h_{A_1}(1) = 0.913 \pm 0.042$$

EXPERIMENT

We begin with 3.3 Million $e^+e^- \to \Upsilon(4S) \to B\bar{B}$ events collected using the CLEO II detector at the symmetric collider CESR.

We fully reconstruct D^{*+} candidates in the decay chain

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



We reconstruct and identify lepton (e or μ) candidates using cylindrical drift chambers and a crystal calorimeter and muon counters.

We require p_e=0.8–2.4 GeV/c and p_μ=1.4–2.4 GeV/c.

Signal and Backgrounds

The $D^*\ \ell$ pairs may come from different sources:

- $D^*\ell\nu$ events
- $D^*X\ell\nu$ events including $D^{**}\ell\nu$ and $D^*\pi\ell\nu$
- combinatoric background ($\sim 6\%$)
  - fake D^{*+} candidates
  - estimated from events in the Δm sideband.
- continuum background ($\sim 4\%$)
  - from $e^+e^- \to q\bar{q}$ q = u, d, s, c
  - subtracted using data below the $B\bar{B}$ threshold
- uncorrelated background ($\sim 4\%$)
  - real D^{*+} and ℓ from different B's
  - estimated using inclusive D^{*+} and ℓ yields
- correlated background ($\sim 0.5\%$)
  - real D^{*+} and ℓ from same B
  - *e.g.* $B \to D^*D_s$ with $D_s \to \ell X$
  - estimated using MC

We fit for $D^*\ell\nu$ and $D^*X\ell\nu$ after subtracting other sources of $D^{*+}\ \ell$ pairs.

We separate $D^*\ell\nu$ and backgrounds from $D^*X\ell\nu$ using kinematics.

$$\cos\theta_{B-D^*\ell} = \frac{2E_B E_{D^*\ell} - M_B^2 - M_{D^*\ell}^2}{2|\vec{p}_B||\vec{p}_{D^*\ell}|}$$

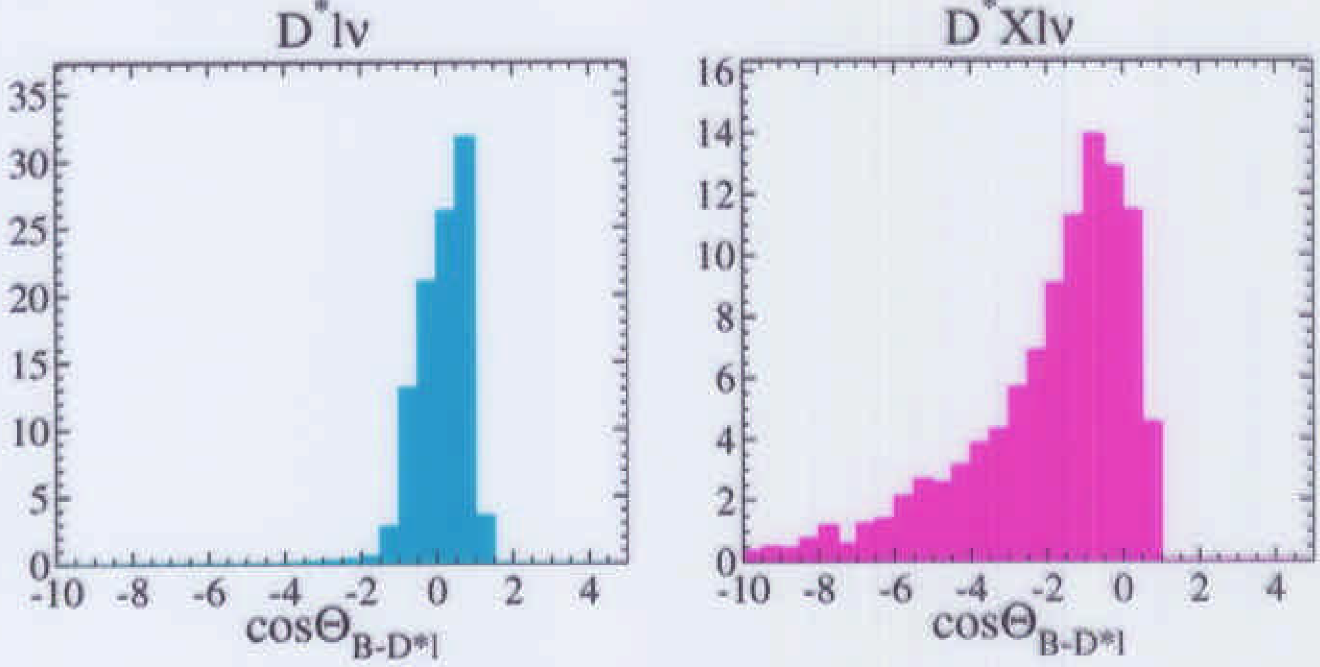
$\cos\theta_{B-D^*\ell}$ can be determined using 4-momentum conservation,

$$p_B = (p_{D^*} + p_\ell) + p_\nu,$$

and the constraints

$$p_\nu^2 = m_\nu^2 = 0 \quad \text{and} \quad E_B = \sqrt{p_B^2 + m_B^2} = E_{\text{beam}}.$$

For signal events, $\cos\theta_{B-D^*\ell} \in (-1, 1)$, allowing separation of $D^*\ell\nu$ from background.



We separate $D^*\ell\nu$ and $D^*X\ell\nu$ events by fitting $\cos\theta_{B-D^*\ell}$.

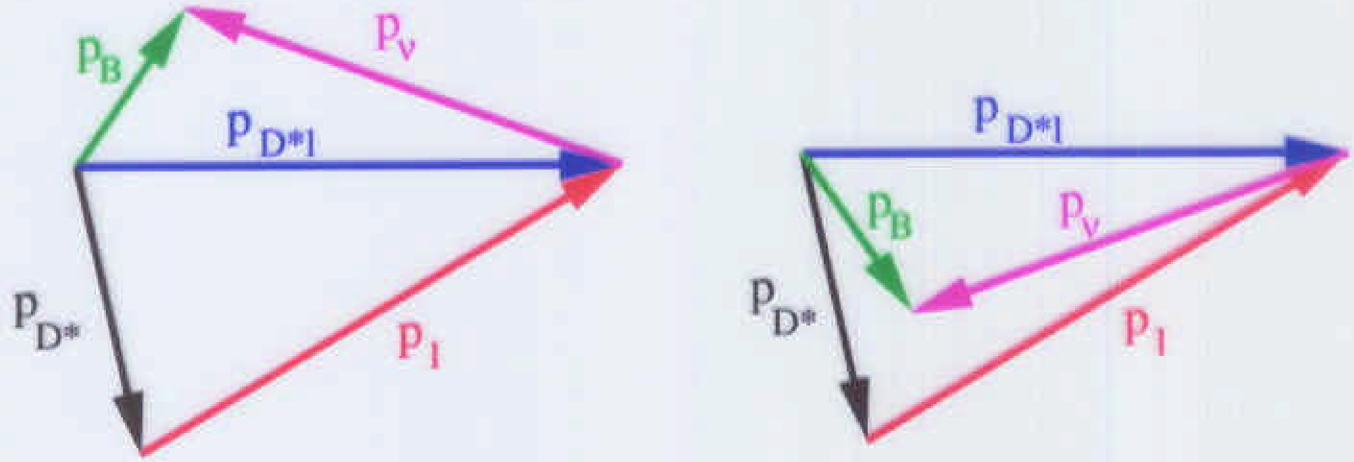
MEASURING w

$w \in (1, 1.51)$ is the Lorentz boost of the D^* in the B rest frame.

At symmetric colliders, the B's are nearly at rest: $p_B \approx 300$ MeV/c.

We know the magnitude but not the direction of the B momentum. It is determined up to an azimuthal ambiguity.

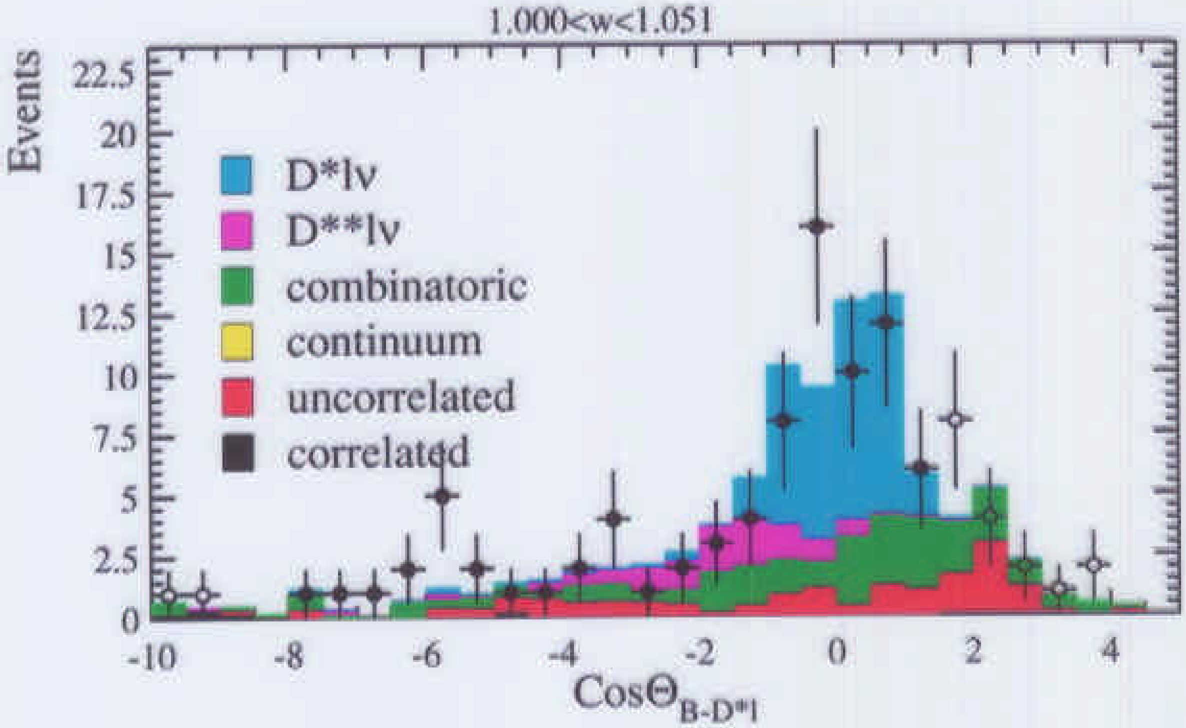
We compute w using the two extreme possibilities for the B direction.

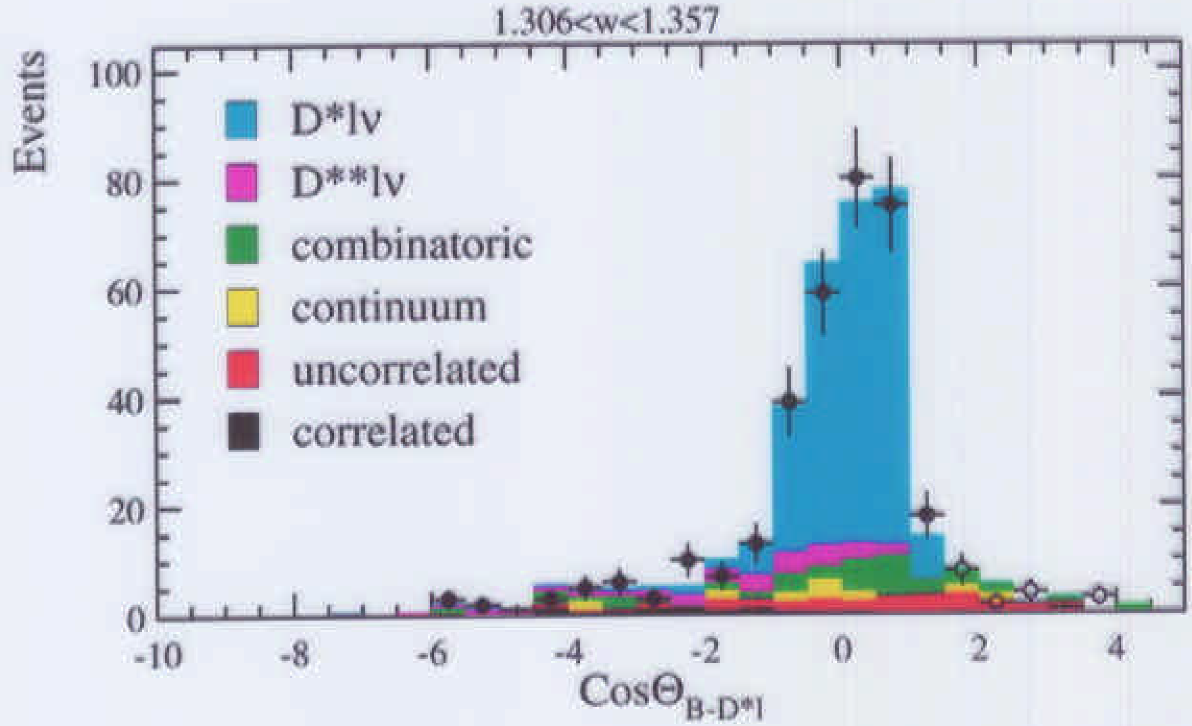


The resolution is good: $\sigma_w \approx 0.03$

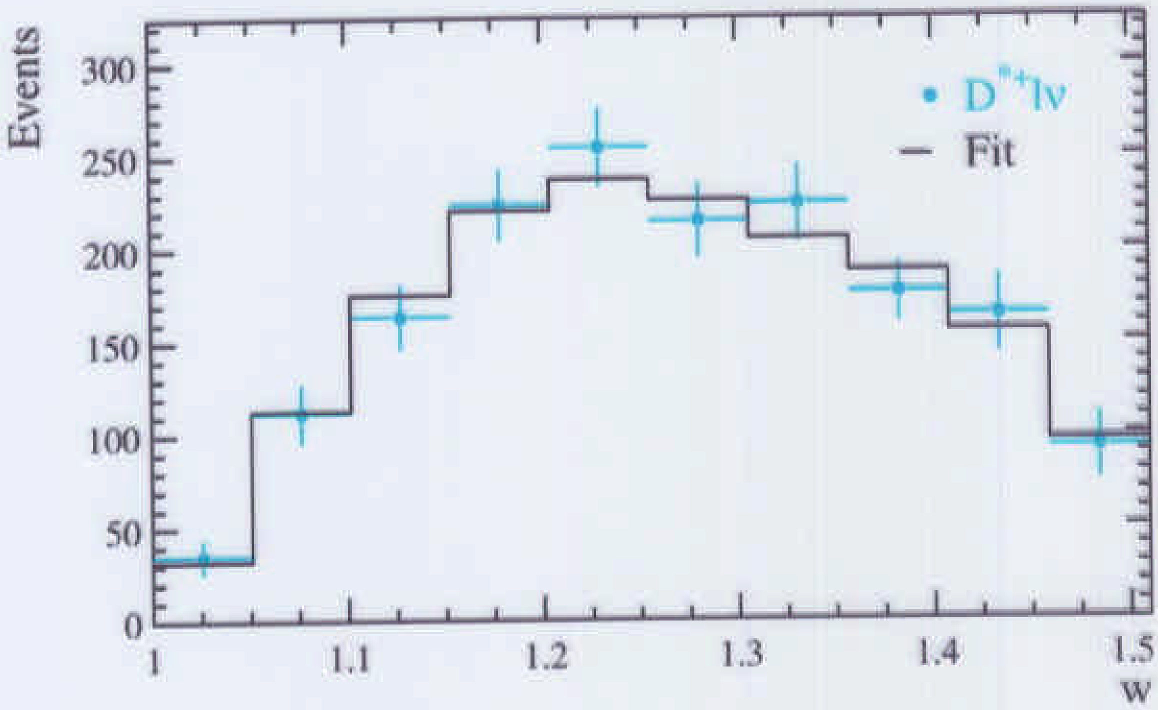
We measure $d\Gamma/dw$ by fitting $\cos\theta_{B-D^*\ell}$ for the yield of $D^*\ell\nu$ events in ten bins of w.

Representative Fits





FITTING $d\Gamma/dw$



$$\chi^2 = \sum_{i=1}^{10} \frac{[N_i^{obs} - \sum_{j=1}^{10} \epsilon_{ij} N_j]^2}{\sigma^2_{N_i^{obs}}}$$

N_i^{obs} = yield in the i^{th} w bin

N_j = number of decays in the j^{th} w bin

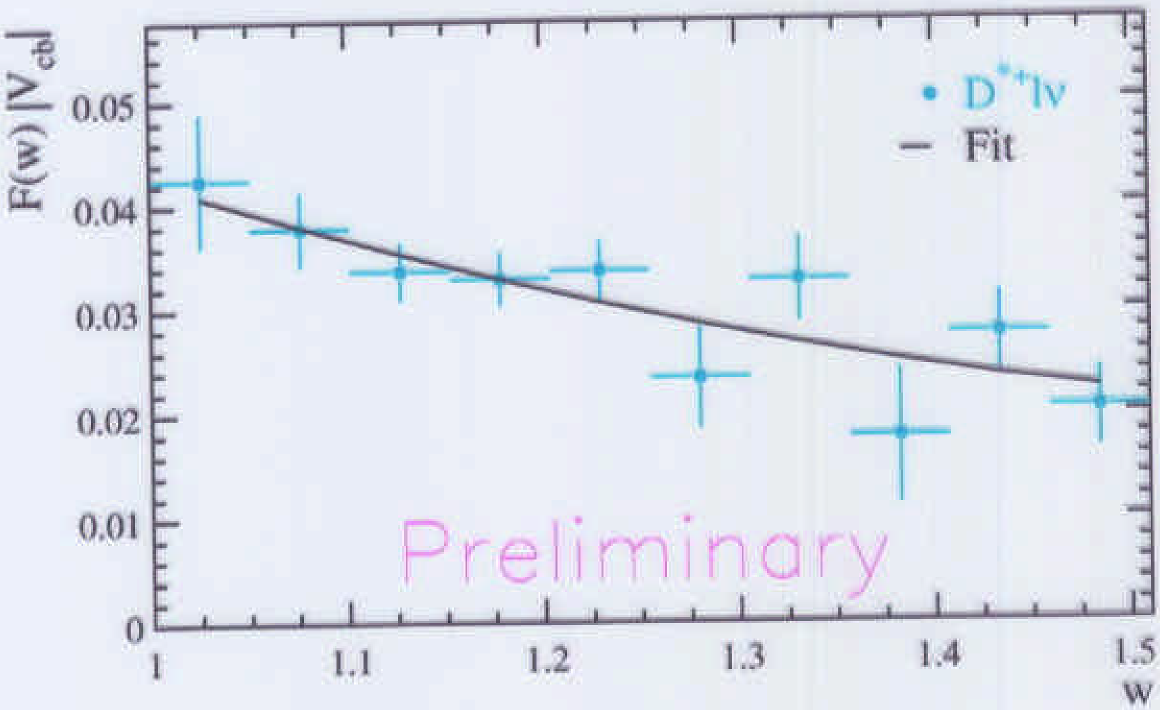
ϵ_{ij} accounts for the reconstruction efficiency and the smearing in w.

$$N_j \;= 4fN_{\Upsilon(4S)}\mathcal{B}(D^* \to D\pi)\mathcal{B}(D \to K\pi)\tau_B \int_{w_j} dw d\Gamma/dw$$

We use the form factor of Caprini, Lellouch and Neubert (NP**B**530, 153) and fit for $\mathcal{F}(1)|V_{cb}|$ and $\rho^2_{h_{A_1}}(w=1)$.

Dispersion Relation Constraint

Fit Results



The fit gives

$$\mathcal{F}(1)|V_{cb}| = (42.4 \pm 1.8 \pm 1.9) \times 10^{-3}$$
$$\rho^2_{h_{A_1}} = (1.67 \pm 0.11 \pm 0.22),$$

with correlation coefficient $C(\mathcal{F}(1)|V_{cb}|, \rho^2) = 0.90$.

Integrating $d\Gamma/dw$ we find

$$\Gamma(\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}) = (0.0366 \pm 0.0018 \pm 0.0023)\ \mathrm{ps}^{-1}$$
$$\mathcal{B}(\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}) = (5.66 \pm 0.29 \pm 0.33)\%$$

Preliminary

Systematic Errors

Source	$\lvert V_{cb}\rvert\mathcal{F}(1)(\%)$	$\rho^2(\%)$	$\Gamma(B \to D^*\ell\nu)(\%)$
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**

Conclusion and Summary

We measure

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

From theory

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

which gives

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

Preliminary

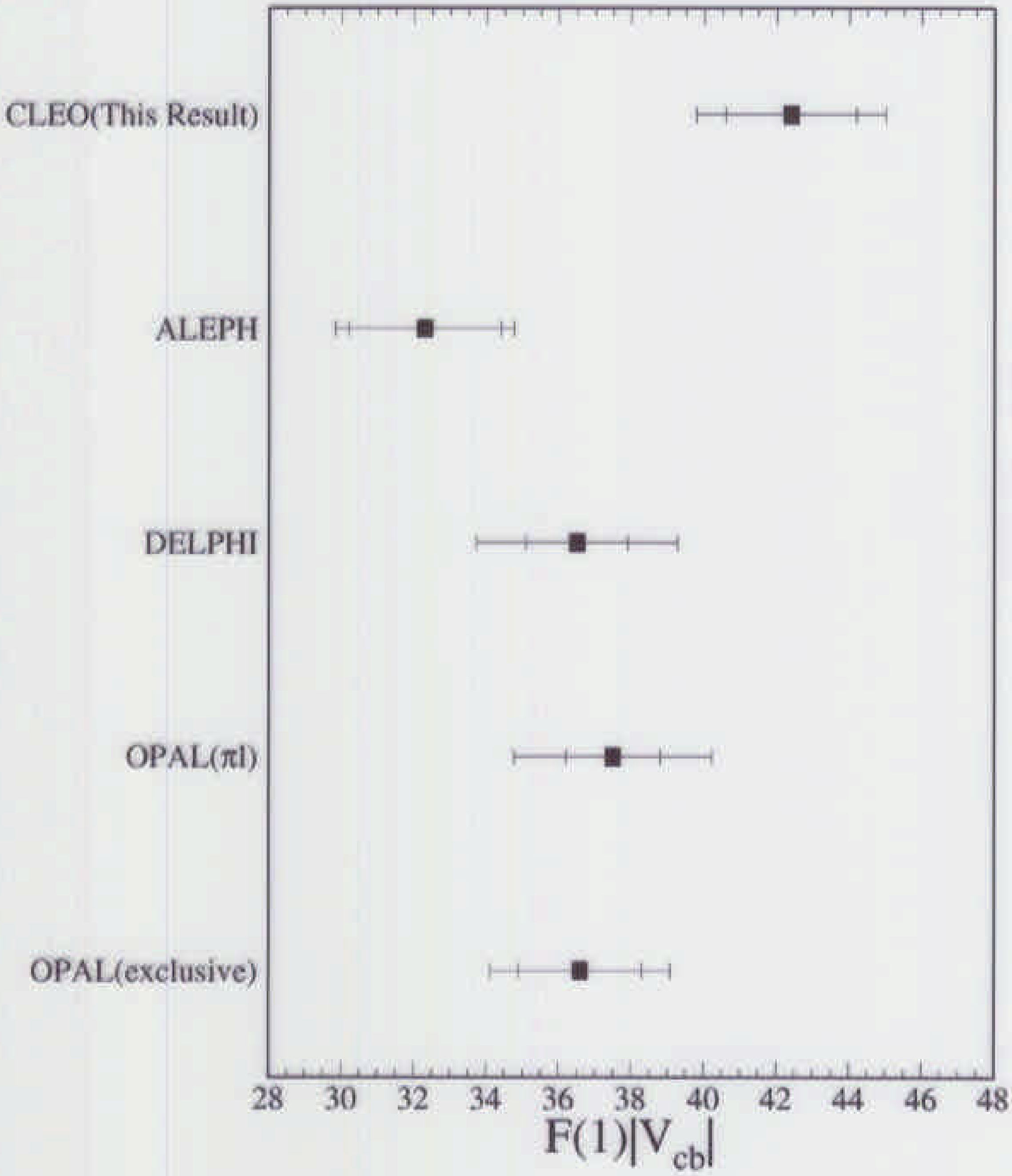
These results are

- consistent with CLEO's 1995 measurement
- comparable to LEP measurements but somewhat larger

I have presented a measurement of $\mathcal{F}(1)|V_{cb}|$ with a

- statistical error 4.2%
- systematic error 4.4%

Combined with $D^{*0}\ell\nu$ this will be the best single measurement of $|V_{cb}|$ from exclusive decays.


CLEO(This Result)
ALEPH
DELPHI
OPAL(πl)
OPAL(exclusive)
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F(1)|V_cb|