Dinosaurs to Cavemen: 10 mins on Exclusive Semileptonic B Decays

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Generalities

$$\frac{\mathrm{d}\Gamma(B \to D^*\ell\bar\nu)}{\mathrm{d}w} = \frac{G_F^2 m_B^5}{48\pi^3} r_*^3 (1-r_*)^2 \sqrt{w^2-1}\,(w+1)^2$$

$$\times \left[1 + \frac{4w}{1+w}\frac{1-2wr_*+r_*^2}{(1-r_*)^2}\right] |V_{cb}|^2 \mathcal{F}_*{}^2(w$$

$$\frac{\mathrm{d}\Gamma(B \to D\ell\bar\nu)}{\mathrm{d}w} = \frac{G_F^2 m_B^5}{48\pi^3} r^3 (1+r)^2 (w^2-1)^{3/2} |V_{cb}|^2 \mathcal{F}^2(w$$

- $w = v \cdot v' = (m_B^2 + m_{D^{(*)}}^2 - q^2)/(2m_B m_{D^{(*)}})$
  $r_{(*)} = m_{D^{(*)}}/m_B$
- $\mathcal{F}(w) = \mathcal{F}_*(w) = \xi_{IsgurWise}(w)$ when $m_Q \to \infty \Rightarrow$
  $\mathcal{F}(1) = \mathcal{F}_*(1) = 1$

Strategy

- Measure rate $\Rightarrow$ $|V_{cb}|\mathcal{F}_*(w)$ at some w's
- Extrapolate to $w = 1$
- Obtain $|V_{cb}|\mathcal{F}_*(1) \approx |V_{cb}|$

Normalization

$$\mathcal{F}_*(1) = 1 + c_A(\alpha_s) + \frac{0}{m_Q} + \frac{(\ldots)}{m_Q^2} + \ldots$$

$$\mathcal{F}(1) = 1 + c_V(\alpha_s) + \frac{(\ldots)}{m_Q} + \frac{(\ldots)}{m_Q^2} + \ldots$$

- perturbative $c_A = -0.04$ and $c_V = 0.02$, to order α_s^2 (Czarnecki and Melnikov)
- Luke's theorem: $\mathcal{O}\left(\Lambda_{\text{QCD}}/m_Q\right)$ in $\mathcal{F}_*(1)$ vanishes
- Rest " $(\ldots)$" hard but small $\Rightarrow$ A. El-Khadra talk yesterday

Extrapolation

- Unavoidable? Question of money and time:
  - If th-error($\mathcal{F}_{(*)}(1)$)$= a \Rightarrow N(B \to D^* \ell \bar{\nu}) \sim a^{-7/2}$ and $N(B \to D \ell \bar{\nu}) \sim a^{-9/2}$ for comparable statistical error in $|V_{cb}|\,\mathcal{F}_{(*)}(1)$ without assumptions about FF shapes
  - Use $a \approx (\Lambda_{\rm QCD}/m_Q)^2$ (or eventual lattice accuracy): $(2\%)^{-7/2} \sim 10^6$.
- Analyticity, Causality and all that nonsense (Boyd, BG, Lebed) CAVEMEN: This is solid
  - Constrains shape
  - Given a slope value (from experiment) some curvature may be unavoidable
    $\Rightarrow$ straight line extrapolation may be inconsistent with QCD

Linear vs physics-based

Form Factor	$\rho^2_{\mathcal{F}}$	$c_{\mathcal{F}}$	$10^2 \lvert V_{cb} \rvert \mathcal{F}(1)$
Linear	0.76±0.16	$\cdots$	4.05±0.45
Parabolic	$0.77^{+1.18}_{-2.83}$	$0.01^{+1.70}_{-3.96}$	$4.05^{+1.51}_{-1.63}$
Boyd et al	1.30±0.27	1.21±0.31	4.48±0.61
Caprini et al	1.27±0.25	1.18±0.26	4.44±0.58

$$\mathcal{F}(w) = \mathcal{F}(1) \left[1 - \rho^2_{\mathcal{F}} (w-1) + c_{\mathcal{F}} (w-1)^2 + \cdots \right]$$

CLEO, PRL82(1999)3746

Slopes

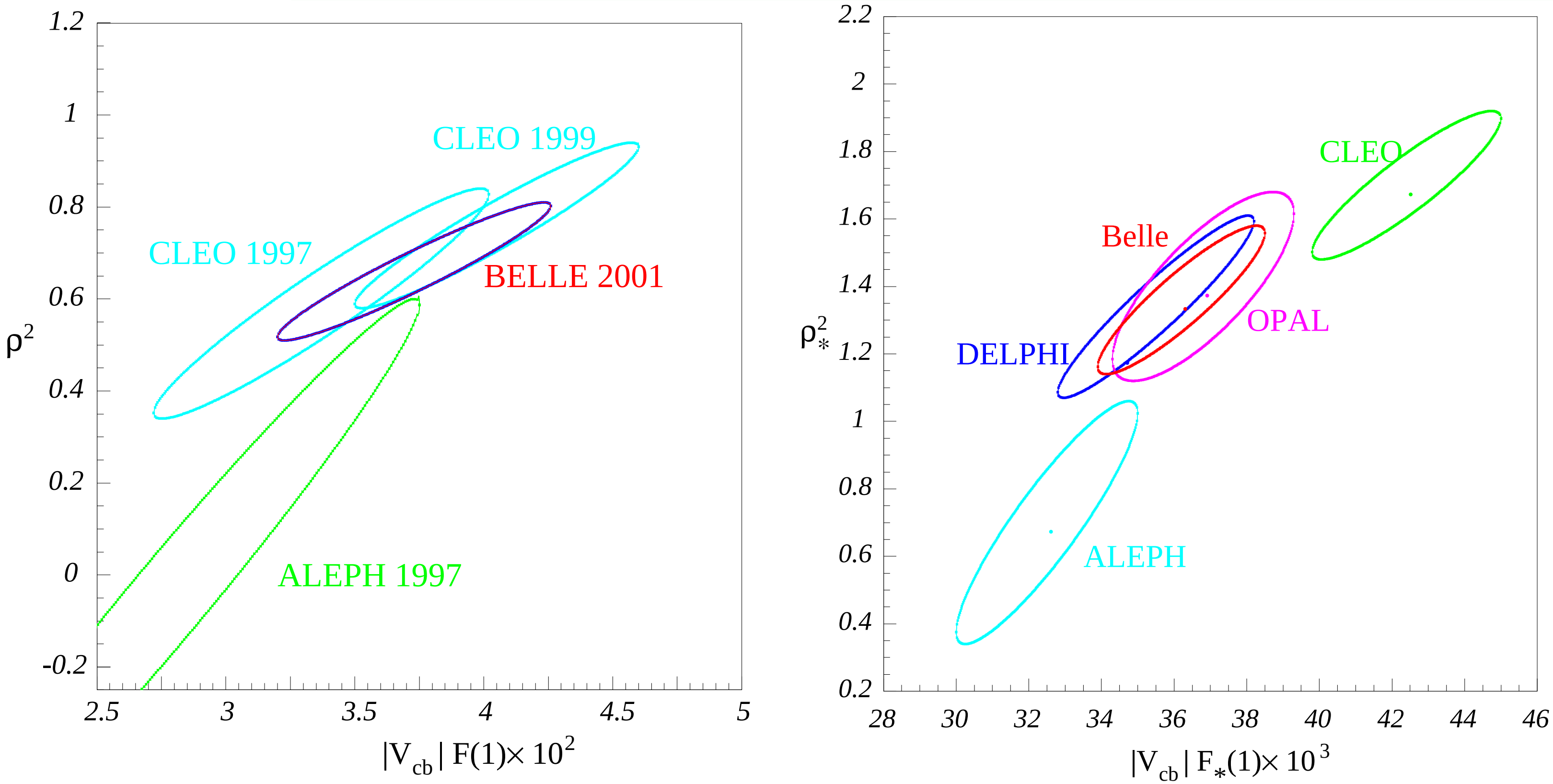
Fitted slope parameter	CLEO[a]	BELLE[b]
$B \to D^* \ell \bar{\nu}$, unitarity–$\rho^2_{A_1}$	$1.67 \pm 0.11 \pm 0.22$	$1.35 \pm 0.17 \pm 0.1$
$B \to D^* \ell \bar{\nu}$, linear–$\rho^2_{\mathcal{F}_*}$	$0.98 \pm 0.09 \pm 0.07$	$0.89 \pm 0.09 \pm 0.0$
$B \to D \ell \bar{\nu}$, unitarity–$\rho^2_{\mathcal{F}}$	$1.30 \pm 0.27 \pm 0.14$	$1.16 \pm 0.25 \pm 0.1$
$B \to D \ell \bar{\nu}$, linear–$\rho^2_{\mathcal{F}}$	$0.76 \pm 0.16 \pm 0.08$	$0.69 \pm 0.14 \pm 0.0$

$$\frac{\langle D^*(v',\epsilon)|\,\bar{c}\,\gamma^\mu\gamma_5\,b\,|B(v)\rangle}{\sqrt{m_{D^*}\,m_B}} = h_{A_1}(w+1)\,\epsilon^{*\mu} - (h_{A_2}v^\mu + h_{A_3}v'^\mu)\,(\epsilon$$

[a] hep-ex/0007052, PRL82(1999)3746, Prv comm, K. Ecklund

[b] hep-ex/0111060, hep-ex/0111082, Prv comm, H. Jang

Infamous Figure



- HQ-symmetry $\Rightarrow \quad \rho^2_{\mathcal{F}} = \rho^2_{\mathcal{F}_*}$
- HQ bad? Abandon strategy? Ans: No, apples vs oranges

Slope Differences, Theory(ZL& BG)

$$\rho^2_{\mathcal{F}} - \rho^2_{\mathcal{F}_*} = 0.243 + 0.075\,\eta(1) + 0.14\,\eta'(1) + 1.0\,\chi_2(1) - 3.0\,\chi_3'(1) - 0.018\,\lambda_1/\text{GeV}^2 \simeq 0.1$$

$$\rho^2_{A_1} - \rho^2_{\mathcal{F}_*} = 0.099 + 0.131\eta(1) + 0.25\chi_2(1) - 0.007\,\lambda_1/\text{GeV}^2 \simeq 0.17$$

- $\eta(w)$, $\chi_i(w)$, etc, non-perturbative effects in $1/m_Q$ expansion
- Large cancellations. χ_1 cancells altogether
- May determine some from curvature differences and FF ratios ($R_1(1)$ and $R_2(1)$)
- wrong direction (sign)

Conclusions

- Use correct extrapolation
- Understand slope differences
- Combine $B \to D\ell\nu$ and $B \to D^*\ell\nu$ for better V_{cb} (only after previous)