V_{cb}: experimental and theoretical highlights

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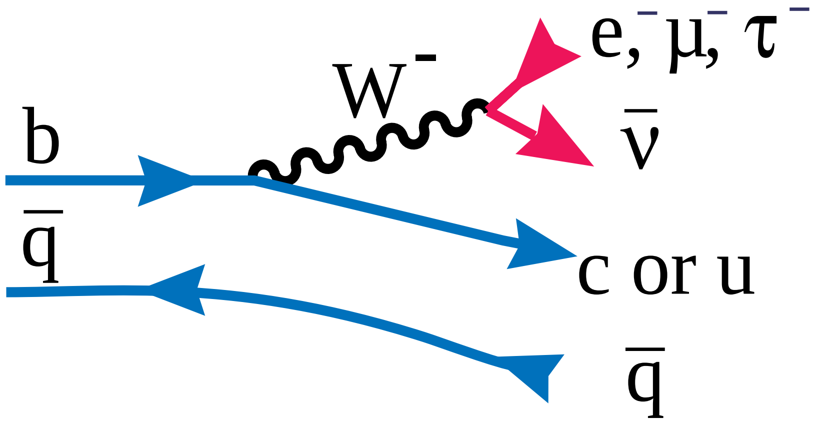
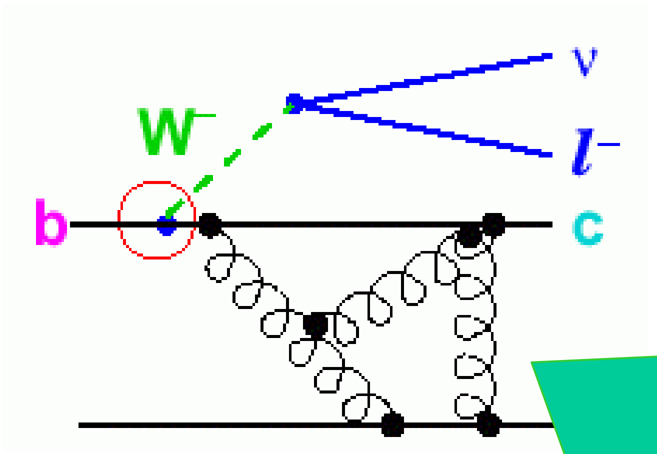
The method





- Ultimate goal: a precise determination of V_{cb}
- The challenge: precise evaluation of the hadronic matrix element

The exclusive approach: HQET & V_{cb}

- Heavy Quark Effective THEORY (HQET) (Isgur & Wise)
  - QCD is flavor independent, so in the limit of infinitely heavy quarks $q_a \rightarrow q_b$ occurs with unit form-factor [F(1)=1] when the quarks are moving with the same invariant 4-*velocity*, w=1.
  - Example: for $B \rightarrow D^* \ell \nu$:
    - All form-factors are related to one universal shape that can be measured
    - Corrections to F(1) due to finite quark masses are calculable along with QCD corrections. These corrections are parameterized in a series: $\Sigma_n C_n (1/m_{qi})^n$, n=1, 2…

V_{cb} from $B \to D^* \ell \nu$

- HQET:

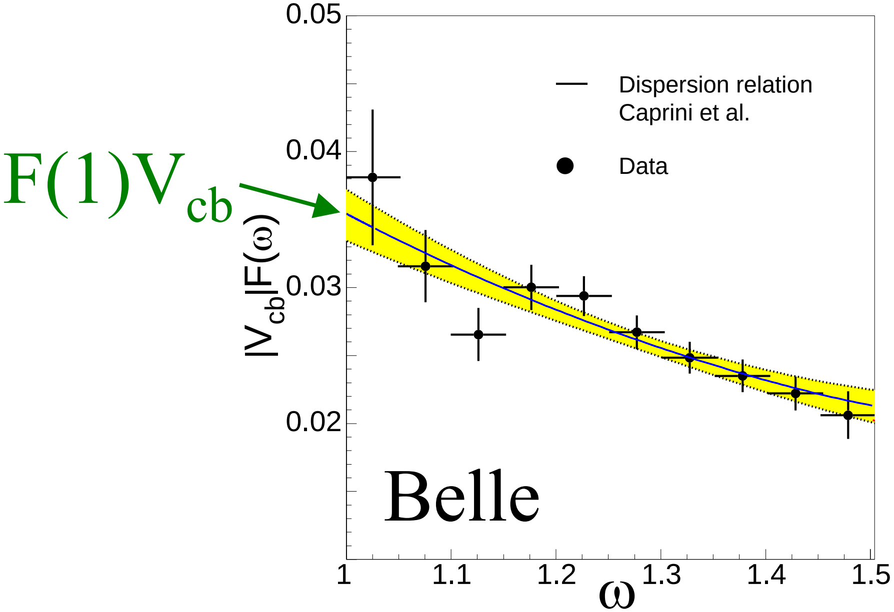
$$\frac{d\Gamma}{dw} = \mathcal{K}(w)\mathcal{F}^2(w)\left|V_{cb}\right|^2$$

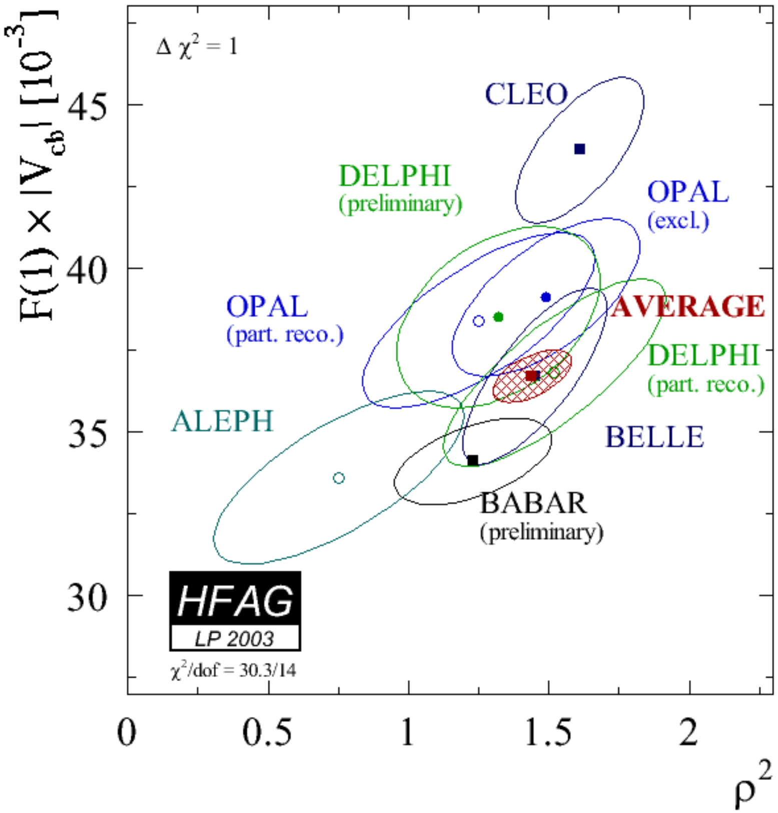
$$\mathcal{F}(w) = \boxed{\mathcal{F}_{D^*}(1)}\, g(w)$$

th

- The shape, $g(w)$ not a clearly predictable quantity, but is constrained by theoretical bounds and measured form factors
- Experiments can measure $d\Gamma/dw$
- To find V_{cb} measure value of decay rate at $w=1 \to F(1)|V_{cb}|$

$F(1)|V_{cb}|$ using $B\rightarrow D^{*}\ell\nu$



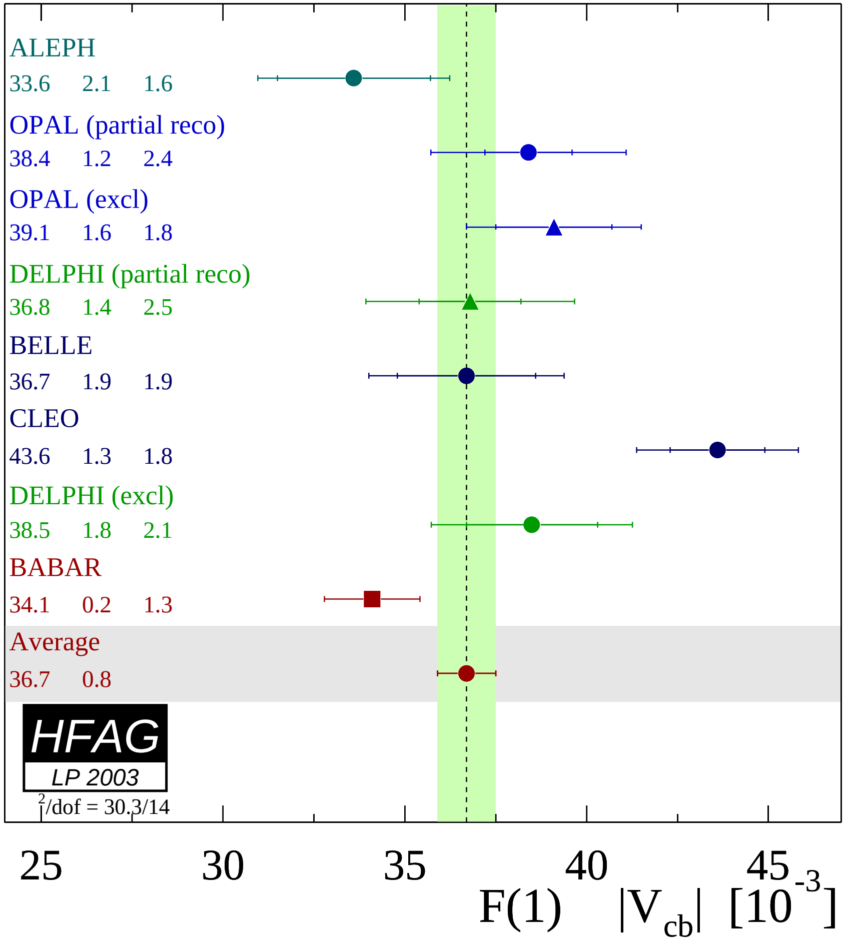


- Fit to function shape given by Caprini et al.
- Yields value of $F(1)|V_{cb}|$ & shape, parameterized by ρ^2.
- $F(1)|V_{cb}| = (36.7 \pm 0.8)\times 10^{-3}$ *(HFAG)*
- $\rho^2 = 1.44 +/- 0.14$ *(HFAG)*

Theoretical calculations of F(1)

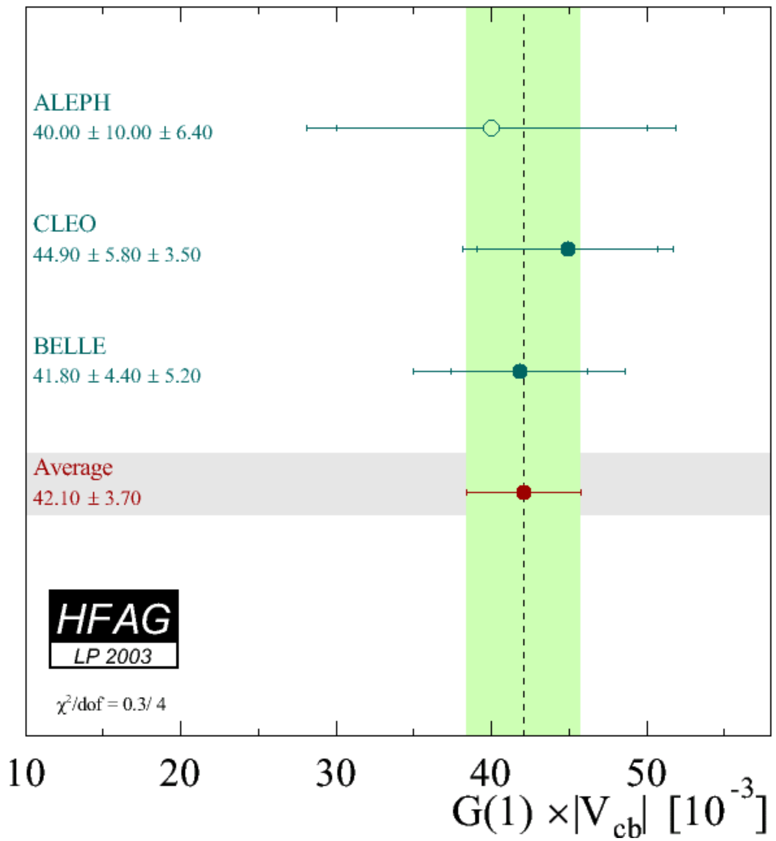
- $F(1)=\eta_{QED}\eta_{QCD}(1+\delta_{1/m^2}+\dots)$
  - Lukes theorem: no $\delta_{1/m}$ corrections *(would be in $D\ell\nu$)*
  - $\eta_{QED}=1.007$, $\eta_{QCD}=0.960\pm0.007$ at two loops
  - δ_{1/m^2} involves $1/m_b^2$, $1/m_c^2$, $1/m_c m_b$
- First Lattice Gauge calculations (quenched-no light quark loops) $0.913^{+0.024+0.017}_{-0.017-0.030}$ ultimate solution
- PDG (Artuso & Barberio) $F(1)=0.91\pm0.05$

V_{cb} Exclusive Averages



$$V_{cb}^{excl} = (40.03 \pm 0.9_{exp} \pm 1.8_{th}) \times 10^{-3}$$

Another exclusive channel: $B \to D \ell \nu$



- Renewed interest on this channel:
  - Lattice calculations
  - QCD sum rules evaluation of G(1)
- Using G(1)=1.058 ±0.07 (Artuso-Barberio PDG2002)

$V_{cb}=(39.8 \pm 3.5_{exp} \pm 2.9_{th})\times 10^{-3}$

$|V_{cb}|$ from inclusive $B \to X_c \ell \nu$

- From $\mathcal{B}(B \to X_c \ell \nu)$ extract the experimental decay width: $$\Gamma_{sl}^{c} \equiv \frac{\mathrm{B}(b \to X_c l \nu)}{\tau_b}$$
- Compare with the theoretical prediction from Operator Product Expansion:

$$\Gamma_{sl}^{c} = \frac{G_F^2 m_b^5 |V_{cb}|^2}{192\pi^3}\left[z_0 \left(1 - \frac{\mu_\pi^2 - \mu_G^2}{2m_b^2}\right) - 2\left(1 - \frac{m_c^2}{m_b^2}\right)\frac{\mu_G^2}{m_b^2} - \frac{2\alpha_s}{3\pi} z_0^{(1)} + \ldots\ldots \right]$$

Known phase space factors

The Heavy Quark Expansion

- Theoretical framework: Heavy Quark Expansion:
  - Inclusive properties expressed as asymptotic expansion in terms of the "energy release" m_b-m_c
  - Underlying theoretical accuracy: are all the uncertainties quantified? In particular ansatz of quark-hadron duality.
  - Experimental determination of the Heavy quark expansion parameters, in particular:
    - m_b,m_c at the relevant mass scale
    - μ_π^2 [λ_1] kinetic energy of the b quark
    - μ_G^2 [λ_2] expectation value of chromomagnetic op.

m_b: a multifaceted fundamental parameter

Important for $V_{c(u)b}$

	m_{kin}(GeV)	$\overline{m}_b(\overline{m}_b)$ (GeV)	method
Beneke,Signer, Smirnov	-	4.26±0.12	Sum rules
Melnikov	4.56±0.06	4.20±0.1	Sum rules
Hoang	4.57±0.06	4.25±0.09	Sum rules
Jamin,Pich	-	4.19±0.06	Sum rules, no resummation
Pineda,Yndurain	-	$4.44^{-0.04}_{+0.03}$	ϒ(1S) mass
NRQCD	-	4.28±0.03±0.03±0.10	Lattice HQET (n_f=2)

ϒ expansion

Jet observables sensitive to b mass(LEP)

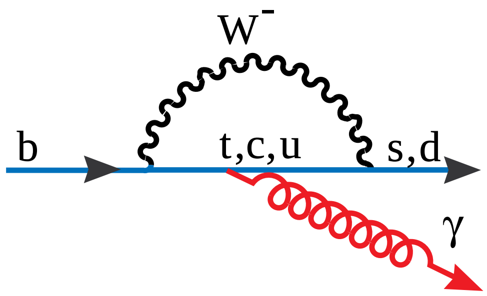
+ pole mass $m_b^{pole} \approx m_{kin} + 0.255$ GeV Bigi-Mannel hep/ph/0212021

Problems with HQE

- Terms in $1/m_b^3$ are multiplied by unknown functions; hard to evaluate error due to these higher order terms
- Duality is assumed: integrated over enough phase space the exclusive charm bound states & the inclusive hadronic result will match at quark-level. But no way to evaluate the error…
- Appears to miss Λ_b lifetime by 10±5% & b-baryon by 18 ±3%; however semileptonic decay may be easier
- Need experimental tests to evaluate errors
  - Sharpen our knowledge of B meson semileptonic decays with high M_x hadronic states
  - Perhaps use V_{cb} as a test?
  - …

How to Measure λ_1 & $\overline{\Lambda}$

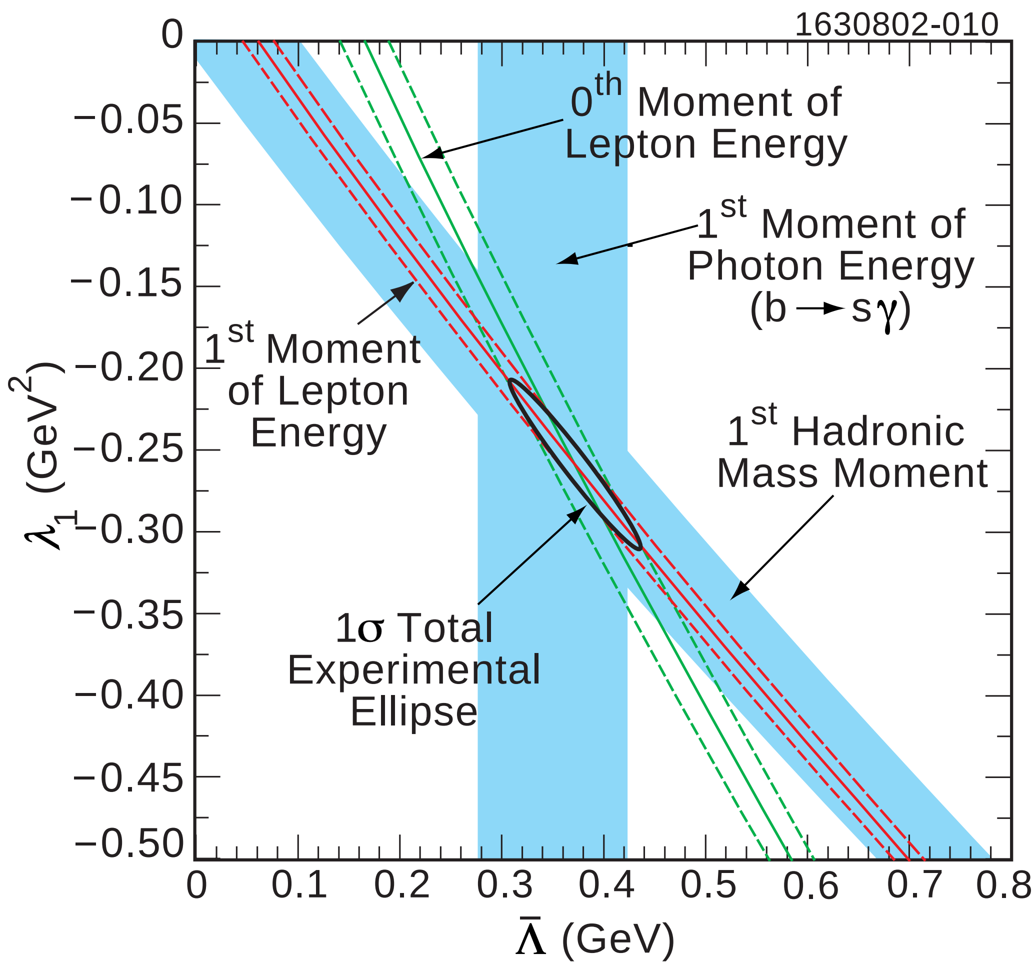
- Can determine λ_1 and $\overline{\Lambda}$, and thus V_{cb} by measuring "moments" in semileptonic decays
  - Hadronic mass moments (ex: $\langle M_X{}^2 - M_D{}^2 \rangle$, M_D is spin-averaged D, D* mass) where $B \to X \ell \nu$
  - Semileptonic moments
- Can also use $b \to s\gamma$ decays,
  here we use the 1st moment
  of the photon energy



Moments (CLEO)

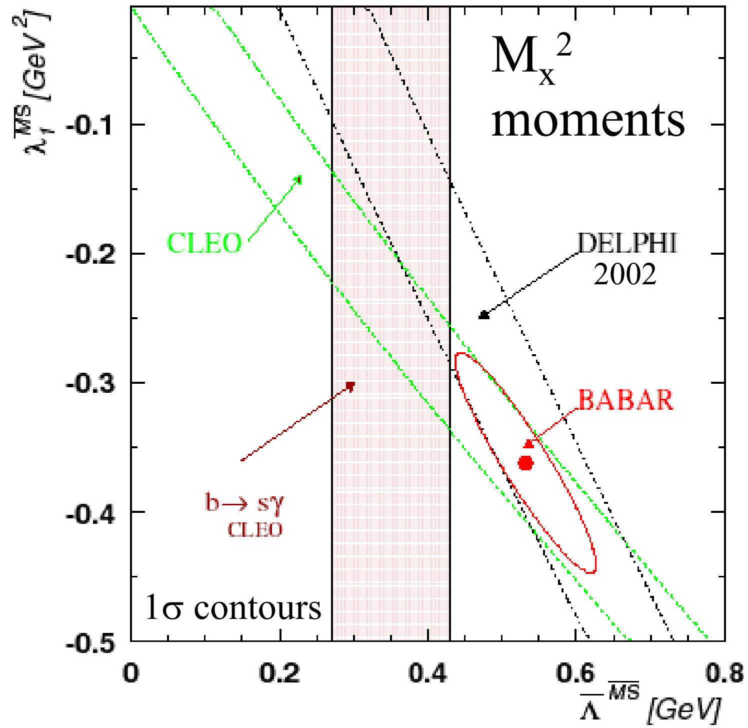
Λ=0.35 ±0.07 GeV
λ_1= -0.24±0.07 GeV^2
exp errors only

- Hadronic Mass & Lepton Energy moments found in semileptonic decays "detecting the neutrino" using missing energy
- $b\rightarrow s\gamma$ moment determination shown later
- Fitting this & other data Bauer, Ligeti, Luke Manohar find $V_{cb}=(40.8\pm0.9)\times10^{-3}$ & $m_b=4.74\pm0.10$ GeV (hep-ph/0210027)



BaBar Moments Result

- Using only BaBar hadronic moments & B_{sl}:
- $V_{cb}=(42.1\pm1.0\pm0.7)\times10^{-3}$ again within $\pm7\%$ of $D^*\ell\nu$
- $m_b^{1S}=4.64\pm0.09\pm0.09$ GeV
- (M_x^2 as function of lepton momentum, is now consistent with theory)

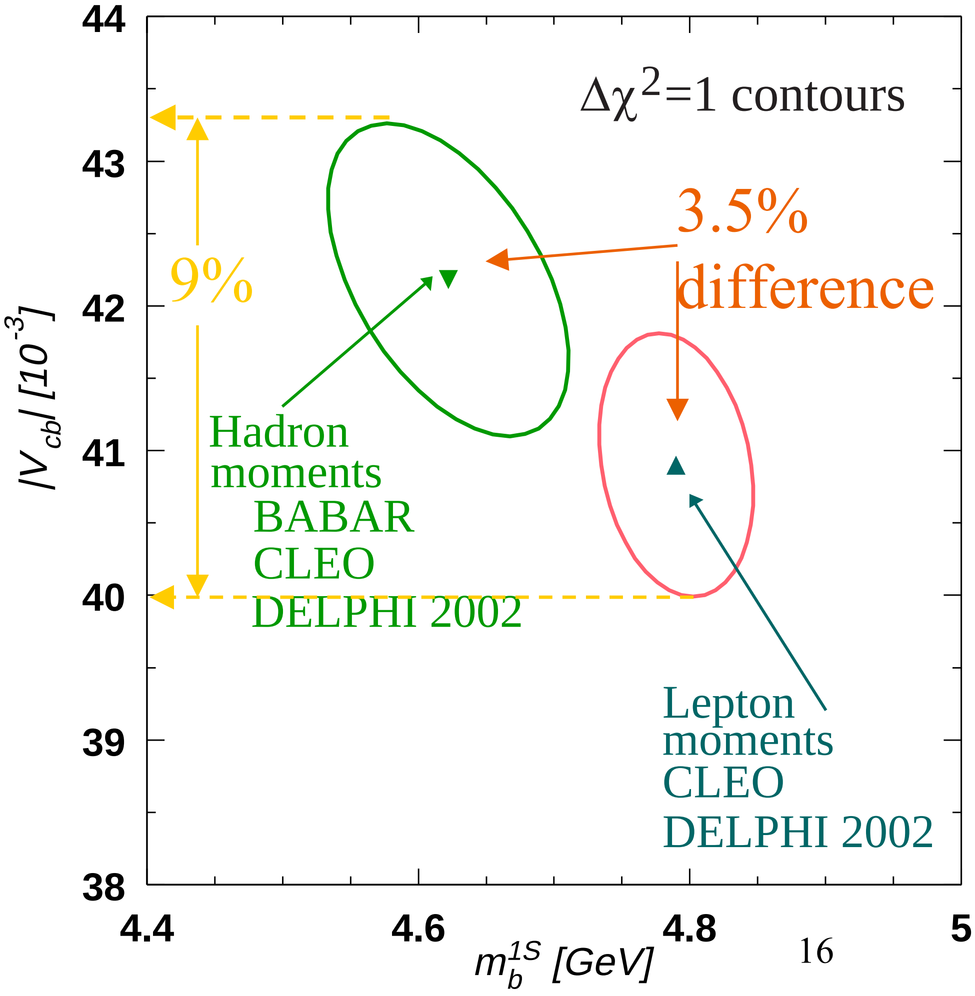


$$\overline{\Lambda}^{\overline{MS}} = 0.53 \pm 0.09_{exp}\,\text{GeV}$$
$$\lambda_1^{\overline{MS}} = -0.36 \pm 0.09_{exp}\,\text{GeV}^2$$

Doesn't include $1/m_b^3$ errors

Comparison of Hadron & Lepton Moments (BaBar)

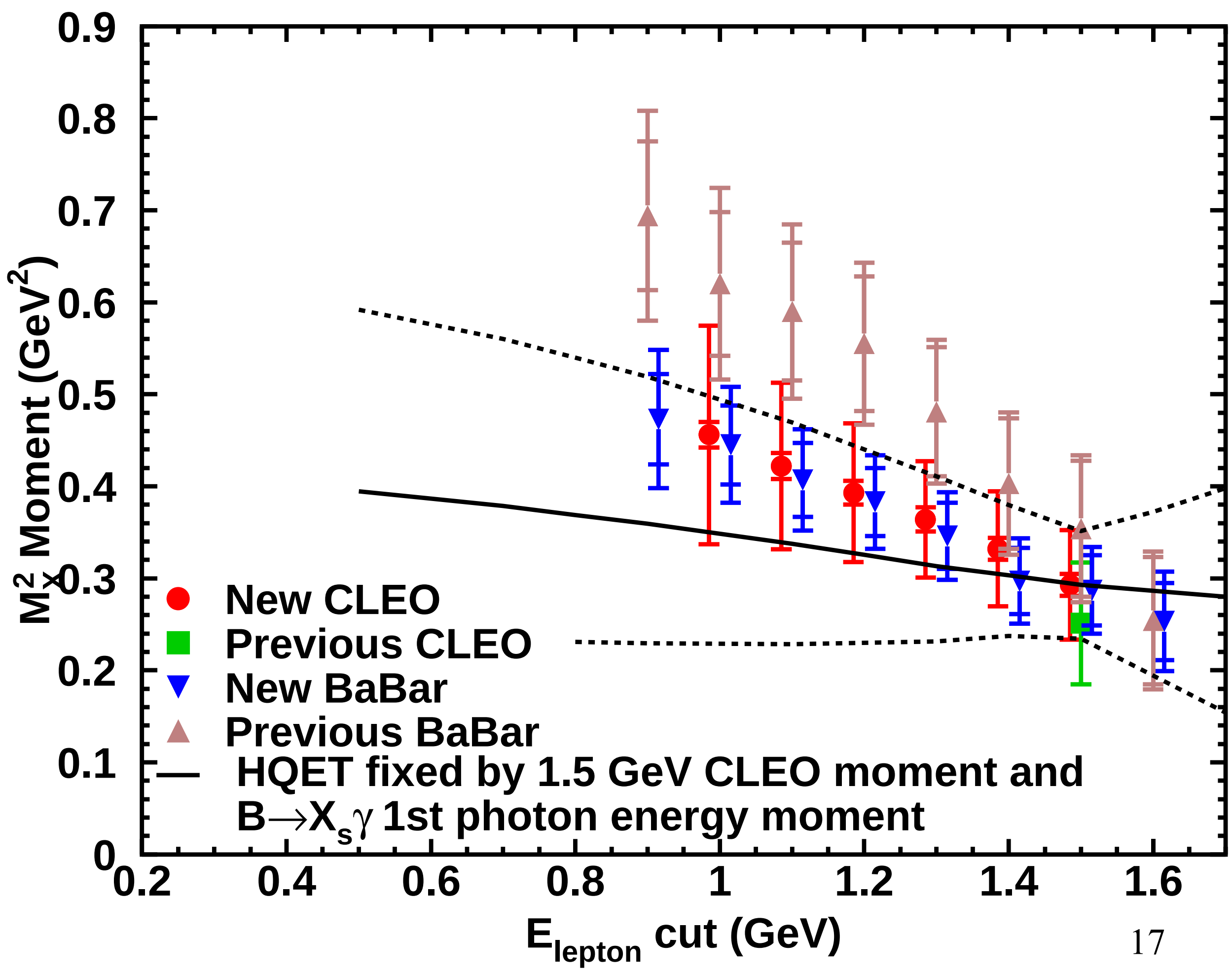
- Lepton & Hadron moments differ somewhat. Does this indicate a Duality violation?
- Difference of 0.2 GeV in m_b leads to 20% difference in V_{ub}



New versus old CLEO & BaBar Moments

Refined experimental results agree with theory.

Can we draw any definitive conclusion?



DELPHI NO E_{lep} cut

$M_x^2 = 0.534 \pm 0.041 \pm 0.074$

Summary of experimental results

- $V_{cb}^{excl}=(40.03\pm0.9_{exp}\pm1.8_{th})\times10^{-3}$

- $V_{cb}^{incl}=(41.5\pm0.4_{\Gamma_{sl}}\pm0.4_{\lambda_1\bar{\Lambda}\,meas}\pm0.9_{th})\times10^{-3}$

my average based on HFAG b.f. and lifetime data

A measure of the consistency between theoretical approaches

Future prospects:

•Precise form factor calculations from lattice gauge calculation

•More extensive exploration of inclusive semileptonic decay observables: in particular high M_x component

•More detailed evaluation & validation of theoretical errors