K. R. Schubert, TU Dresden
XXI Lepton - Photon Symposium
Fermilab, 12 Aug 2003

CKM Matrix Element Magnitudes

St. Model origin, invariants, and parametrisations of V_{CKM}.
$|V_{ud}|$, $|V_{us}|$, $|V_{cd}|$, $|V_{cs}|_1$: Unitary?
$|V_{cb}|$, $|V_{ub}|$, $|V_{td}|$, $|V_{ts}|$, $|V_{cs}|_2$: Unitary? CP-violating?
Parameter values without and with $\varepsilon(K^0)$ and $\sin 2\beta$

Many averaged results are my private guesses,
many references will only be given in the later write-up of this talk.

Yukawa Structure of the St. Model

$$L(\ell,q)=L_{kin}+L_{\text{int}}-\left[C^{(\ell)}_{\alpha\beta}\cdot\overline{\ell}_{R\alpha}\Phi^{+}\begin{pmatrix}\nu_{L\beta}\\ \ell_{L\beta}\end{pmatrix}+C^{(d)}_{\alpha\beta}\cdot\overline{d}_{R\alpha}\Phi^{+}\begin{pmatrix}u_{L\beta}\\ d_{L\beta}\end{pmatrix}+C^{(u)}_{\alpha\beta}\cdot\overline{u}_{R\alpha}\Phi^{T}\varepsilon\begin{pmatrix}u_{L\beta}\\ d_{L\beta}\end{pmatrix}+h.c.\right];$$

$$\Phi=\begin{pmatrix}\Phi_1\\ \Phi_2\end{pmatrix};\quad \alpha,\beta=1,2,3.$$

$C^{(u)}$ and $C^{(d)}$ cannot be diagonalised simultanuously since Glashow married $u_{L\alpha}$ and $d_{L\alpha}$ into doublets. The difference of the two „rotations“ in family space which diagonalize $C^{(u)}$ and $C^{(d)}$ is V_{CKM}.

$$\begin{pmatrix}\begin{pmatrix}u_L\\ d'_L\end{pmatrix}\\ \begin{pmatrix}c_L\\ s'_L\end{pmatrix}\\ \begin{pmatrix}t_L\\ b'_L\end{pmatrix}\end{pmatrix}=V\begin{pmatrix}\begin{pmatrix}u'_L\\ d_L\end{pmatrix}\\ \begin{pmatrix}c'_L\\ s_L\end{pmatrix}\\ \begin{pmatrix}t'_L\\ b_L\end{pmatrix}\end{pmatrix}$$

$$V\,V^{+}=1.$$

V was introduced 1973 by M. Kobayashi and T. Maskawa; is called V_{CKM} since 1987 in recognition of N. Cabibbo 1963.

St. Model allows arbitrary $C^{(u)}$ and $C^{(d)}$ $\Rightarrow$ Standard weak interaction is not CP-invariant.

Invariants of the CKM matrix

In $\mathcal{L}_{\text{St.Model}}$, $\varphi(u_\alpha)$ and $\varphi(d_\beta)$ arbitrary $\Rightarrow V_{\alpha\beta}$ not observable,

$$u_\alpha \to u_\alpha \cdot e^{i\varphi_\alpha}, \; d_\beta \to d_\beta \cdot e^{i\varphi_\beta} \quad \Rightarrow \quad V_{\alpha\beta} \to V_{\alpha\beta} \cdot e^{i(\varphi_\alpha - \varphi_\beta)}$$

Observables are, i. e. invariants under phase transformations

1) $V_{\alpha\beta} V^*_{\alpha\beta} = |V_{\alpha\beta}|^2$

2) $V_{\alpha\beta} V^*_{\alpha\delta} V_{\gamma\delta} V^*_{\gamma\beta}$

3 et al.) $V_{\alpha\beta} V^*_{\alpha\delta} V_{\gamma\lambda} V^*_{\gamma\beta} V_{\kappa\lambda} V^*_{\kappa\delta}$ *et al.*

Parametrisations of the CKM matrix

$V_{\alpha\beta}$ has $2 \cdot 9 - 9 - 5 = 4$ observable parameters

and an infinite number of choices for these 4.

One choice: $|V_{us}|, \; |V_{cb}|, \; |V_{ub}|, \varphi\left(V^*_{ub} V_{ud} V^*_{cd} V_{cb}\right).$

L. Wolfenstein's choice 1983: $|V_{us}| = \lambda, \; |V_{cb}| = A \cdot \lambda^2,$

$$|V_{ub}| \cdot \cos\varphi = A \cdot \lambda^3 \cdot \rho, \; |V_{ub}| \cdot \sin\varphi = A \cdot \lambda^3 \cdot \eta.$$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix};$$

$$V\,V^{+} = 1;$$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \left[\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + o(\lambda^4) \right] \begin{pmatrix} d \\ s \\ b \end{pmatrix}.$$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Three sources:

Super-allowed nuclear β^+-decays

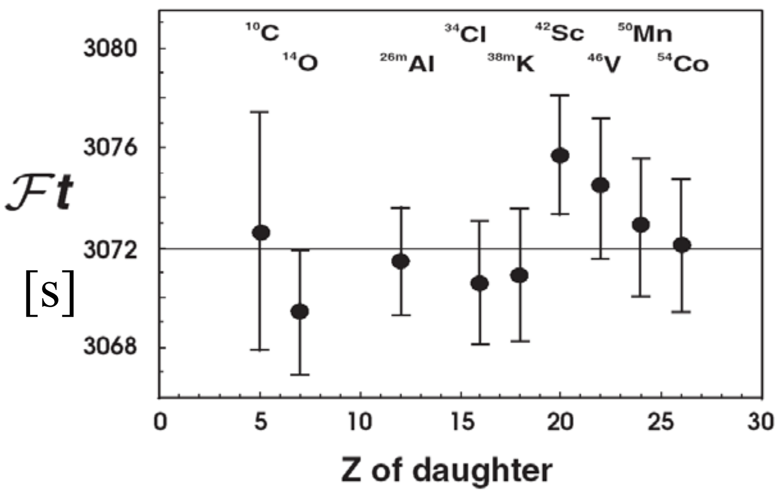
β^- decays of polarized neutrons

β^+ decay of the π^+

Super-allowed nuclear β^+-decays:

$0^+ \rightarrow 0^+$ nuclear transitions within same isospin multiplet, pure V.

I. S. Towner and J. C. Hardy 2003:



$$Ft = (3072.2 \pm 0.9 \pm 1.1)\ s$$

fit error and estimated error on δ_C

$$|V_{ud}|^2 = \frac{2\,\pi^3 \ln 2}{m_e^5} \cdot \frac{1}{2\,G_F^2\,(1+\Delta_{RV})\,Ft},$$

G_F from μ decay, $\Delta_{RV} = (2.40 \pm 0.08)\%$

$|V_{ud}| = 0.9740 \pm 0.0001_{ft,exp} \pm 0.0004_{\Delta} \pm 0.0003_{Ft/ft}$

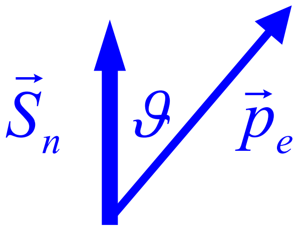
$$Ft = f \cdot t_{1/2} \cdot (1+\delta_R') \cdot (1+\delta_{NS} - \delta_C)$$

$|V_{ud}|_{Nucl} = 0.9740 \pm 0.0005$

β^- decays of polarized neutrons:

V and A transition because of $1/2^+ \rightarrow 1/2^+$. $G_V = G_F\,|V_{ud}|$,

but j_A only partially conserved. Determine $G_A/G_V = \lambda$ experimentally!



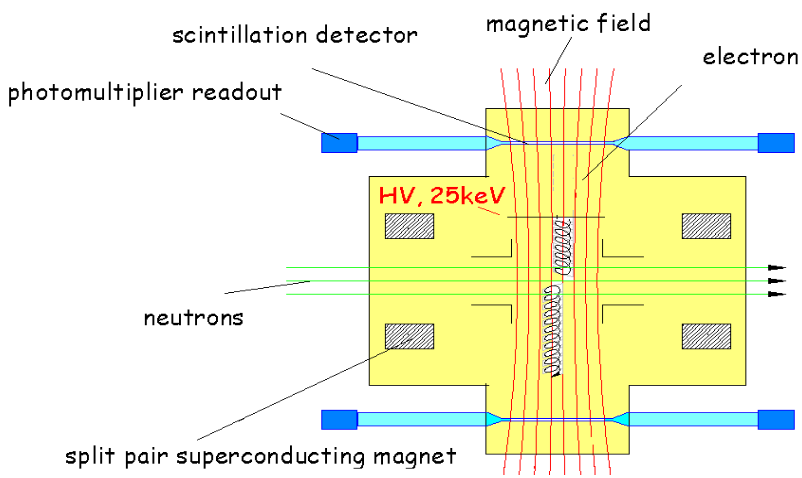
$$W(\vartheta) = 1 + \frac{v}{c} \cdot P \cdot A \cdot \cos\vartheta\,, \qquad A = \frac{-2\lambda(\lambda+1)}{1+3\lambda^2} + o(1\%)$$

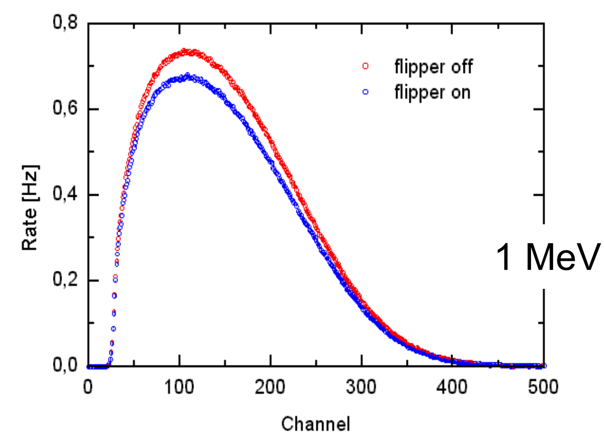
$$\frac{1}{\tau_n} = \frac{m_e^{\,5} \cdot G_F^2 \cdot |V_{ud}|^2}{2\,\pi^3} \cdot \left(1+3\lambda^2\right) \cdot f\left(1+\delta_R\right) \cdot \left(1+\Delta_{RV}\right).$$

Most recent experiment is PERKEO-II at ILL Grenoble;

neutrons of 25 K with P = (98.9 $\pm$ 0.3)%,

periodical spin-flip. e-detector:



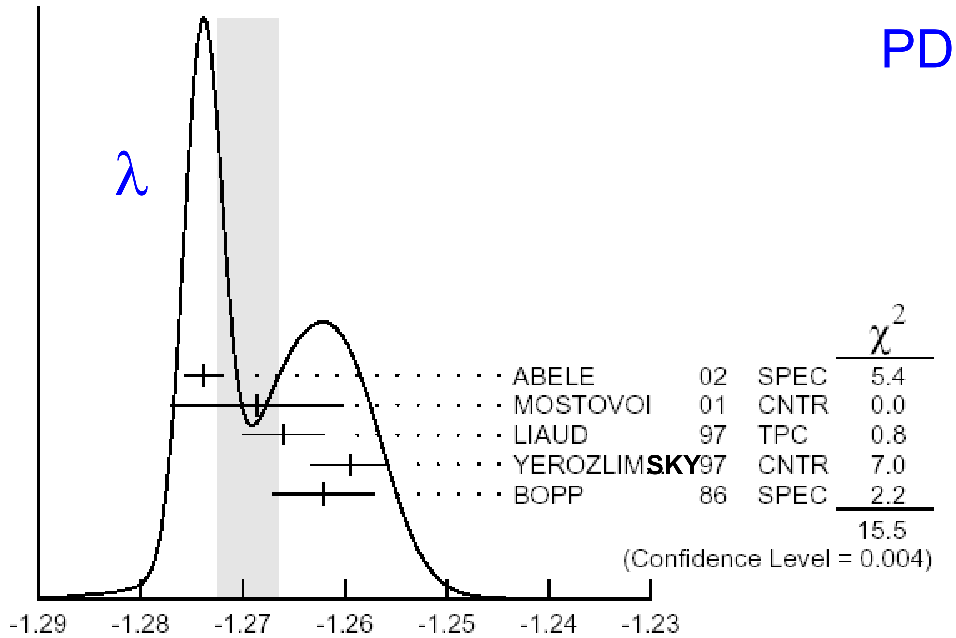


A = -0.1189 (7)

$\lambda = G_A/G_V = -1.2739\ (19)$

PDG 2003: λ = -1.2695 $\pm$ 0.0029

(S = 2.0). τ_n = (885.7 $\pm$ 0.8) s



P	A/A_{raw} - 1
0.989	0.02
0.97	-
0.98	0.15
0.70	0.30
0.98	0.13

$|V_{ud}|_{Nucl}$ = 0.9740 $\pm$ 0.0005

$|V_{ud}|_{n}$ = 0.9741 $\pm$ 0.0020

PERKEO-II (Abele 03, corrected) alone: $|V_{ud}|_{n}$ = 0.9717 $\pm$ 0.0013

β decay of π^+:

Recent experiment PIBETA at PSI; stopped π^+, $\pi^+ \to \pi^0 e^+ \nu_e$, detection of π^0 in CsI ball, normalisation with $e^+\nu_e$. Preliminary result:

$BF(\pi^+ \to \pi^0 e^+ \nu_e)$ = (1.044$\pm$0.007$\pm$0.009) 10^{-8}.

$|V_{ud}|_{\pi}$ = 0.9765 $\pm$ 0.0056

Summary of V_{ud}:

$|V_{ud}|_{Nucl} = 0.9740 \pm 0.0005$ (1)

$|V_{ud}|_{n} = 0.9741 \pm 0.0020$ S = 2.0 (2)

PERKEO-II alone: $|V_{ud}|_{n} = 0.9717 \pm 0.0013$ (3)

$|V_{ud}|_{\pi} = 0.9765 \pm 0.0056$ (4)

Prospects: PIBETA will not reach competitive precision, $\pm$ 0.0030 ?

$\sigma(V_{ud,Nucl})$ dominated by radiative corr.

$\sigma(V_{ud,n})$ dominated by experiment. New experiments are underway, PERKEO 03, „new PERKEO“ 05 , LANL, SNS, Gatchina/PSI

My average: (1) + (3) + (4) with S =1.3 $\Rightarrow$

$|V_{ud}| = 0.9737 \pm 0.0007$

$$\begin{matrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{matrix}$$

Sources: Old K_{l3} decays, new K_{l3} decays, hyperon β-decays, τ decays

K_{l3} decays: $K^+ \to \pi^0 l^+ \nu_e$ and $K^0 \to \pi^- l^+ \nu_e$, $0^- \to 0^-$, pure V

$$\Gamma_i = \frac{m_K^{\ 5} \cdot G_F^2 \cdot |V_{us}|^2}{192\,\pi^3} \cdot C_i^2 \cdot |f_+(0)|^2 \cdot I_i(\lambda_+, \lambda_0) \cdot (1+\delta_R), \quad f_{+,0}(q^2) = f_+(0) \cdot \left(1 + \lambda_{+,0} \frac{q^2}{m_\pi^2} + \dots\right)$$

$$C_i = 1 \big/ \sqrt{2} \ \ for\ K^+\ and\ K_L^0$$

Mode	BR (%)	$10^3 \lambda_+$	$10^3 \lambda_0$
K_{e3}^+	4.87 ± 0.06	27.8 ± 1.9	
K_{e3}^0	38.79 ± 0.27	29.1 ± 1.8	
$K_{\mu 3}^+$	3.27 ± 0.06	33 ± 10	4 ± 9
$K_{\mu 3}^0$	27.18 ± 0.25	33 ± 5	27 ± 6

$$\tau_{K^\pm} = (1.2384 \pm 0.0024) \times 10^{-8}\ s$$

$$\tau_{K_L} = (5.17 \pm 0.04) \times 10^{-8}\ s$$

⇐ Exp. input since ~1980.

Leutwyler and Roos 1984:

$$f_+^{K^0}(0) = 0.961\,,\ f_+^{K^+}(0) = 0.982\,.$$

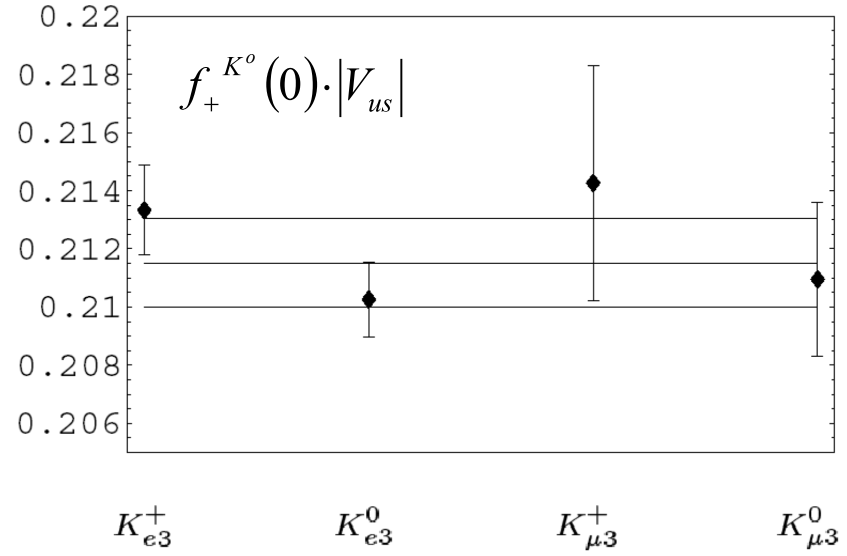
$|V_{us}|_{Kl3,old} = 0.2196 \pm 0.0023$

New theoretical inputs

increase V_{us} by + 0.2% ± 0.2%

V. Cirigliano 2003:

$|V_{us}|_{\text{old } Kl3} = 0.2201 \pm 0.0024$



New K_{l3} results: Final K^+_{e3} result of BNL-E865, hep-ex/0305042

Preliminary KLOE results on three K^0_{l3} rates

BNL-E865: Aim $K^+ \to \pi^+\mu^+e^-$. Dedicated run for $K^+ \to \pi^0 e^+ \nu_e$ during one week 1998, $\pi^0 \to e^+e^-\gamma$. Normalised to $K^+ \to \pi^+\pi^0$, $\pi^+\pi^0\pi^0$. Result:

$$BF(K^+ \to \pi^0 e^+ \nu_e) = (5.13 \pm 0.02 \pm 0.09 \pm 0.04)\%$$

$$= (1.053 \pm 0.024) \cdot BF(\text{old}),\ 2.2\sigma$$

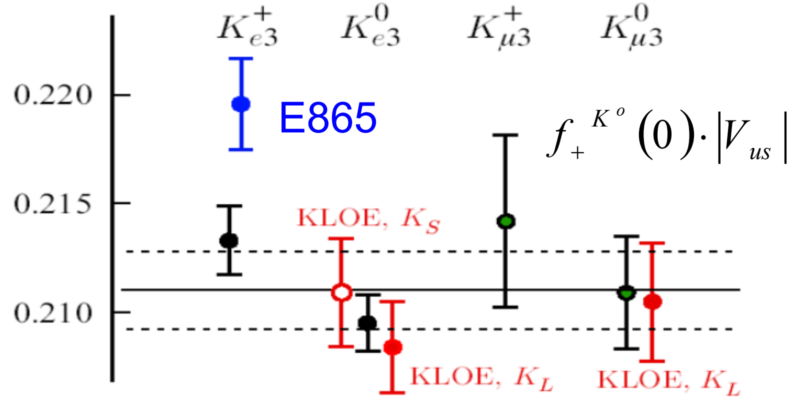
$$\lambda_+ = \lambda_+(\text{old})$$

$|V_{us}|_{Kl3,old} = 0.2201 \pm 0.0016 \pm 0.0018$

$|V_{us}|_{E865} = 0.2285 \pm 0.0023 \pm 0.0019$

using Cirigliano's $f(0)(1+\delta)$,

$3.0\,\sigma$ higher than old K^+K^0 average



$|V_{us}|_{Kl3,old+E865} = 0.2220 \pm 0.0019\ (S=1.5) \pm 0.0018$

KLOE: $e^+e^- \rightarrow \phi(1020) \rightarrow K_S K_L$

hep-ex/0307016 gives preliminary K^0_{l3} results from 78 / pb.

Values only given in this plot (⇈), in agreement with $K_{l3,old}$

Hyperon Decays: revisited by N. Cabibbo et al, hep-ph/0307298.

Exp. data from $n \rightarrow pe\nu$, $\Lambda \rightarrow pe\nu$, $\Sigma^- \rightarrow ne\nu$, $\Xi^- \rightarrow \Lambda e\nu$, and $\Xi^0 \rightarrow \Sigma^+ e\nu$.

New: SU(3) breaking values of „g_A/g_V" = $g_1(0)/f_1(0)$ taken from experiment, compatible with no SU(3) breaking. Using $f_1(0) = 1.000$:

$|V_{us}|_{Hyperons} = 0.2250 \pm 0.0027$. Unknown f(0) error.

Tau decays: $\Gamma(\tau \to K\ n\pi\ \nu) / \Gamma(\tau \to \text{had}\ \nu)$ is sensitive to $|V_{us}|$.

Using ALEPH data and $m_s(2\ \text{GeV}) = (105 \pm 20)$ MeV, Gamiz et al find

$$|V_{us}|_{\tau} = 0.2179 \pm 0.0044_{exp} \pm 0.0009_{th}$$

Dominant error is experimental. Better measurements of rates and mass moments would give both m_s and $|V_{us}|$.

Summary of V_{us}

Prospects for K_{l3}: Final results from KLOE, also on K^+ decays, will come soon. NA48 & KTeV have these decays recorded, but not analysed.

for Hyperons: More theoretical work needed.

for τ decays: BABAR and BELLE have 10^{8} $\tau\tau$ events, should look into their potential to get $\Gamma(\tau \to K\ n\pi\ \nu)$ and mass moments.

My average

from old K_{l3}, E865, and τ decays: $|V_{us}| = 0.2210 \pm 0.0023$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Old source: Production of dimuon pairs by neutrinos on nuclei

$$\nu_\mu\, d \to \mu^-\, c\,,\quad c \to s\, \mu^+\, \nu_\mu$$

$$\bar{\nu}_\mu\, \bar{d} \to \mu^+\, \bar{c}\,,\quad \bar{c} \to \bar{s}\, \mu^-\, \bar{\nu}_\mu$$

with $\boldsymbol{B} = \boldsymbol{BF}(c \to \mu^+ X)$:

$$\frac{\sigma(\nu \to \mu^+\mu^-) - \sigma(\bar{\nu} \to \mu^+\mu^-)}{\sigma(\nu \to \mu^-) - \sigma(\bar{\nu} \to \mu^+)} = \frac{3}{2} \cdot B \cdot |V_{cd}|^2$$

$= (0.41 \pm 0.07)\ \%$ CDHS 1982

$= (0.534 \pm 0.021^{+0.025}_{-0.051})\%$ CCFR 1995

$\boldsymbol{B} = 0.099 \pm 0.012 \Rightarrow$

$|V_{cd}| = 0.224 \pm 0.016$

<u>Prospects:</u> CLEO-c

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Sources: (1) β decays of D mesons and (2) decays of real $W^{\pm}$

$D^+ \to \bar{K}^0 e^+ \nu$ and $D^0 \to K^- e^+ \nu$: $\Gamma = \frac{B}{\tau} = \frac{G_F^2 \cdot |V_{cs}|^2}{192\pi^3} \cdot \Phi \cdot |f(0)|^2 \cdot (1 + \delta_R)$

Constituent quark models and QCD sumrules:

$f(0) = 0.7 \pm 0.1$

$\Rightarrow$ $|V_{cs}| = 1.04 \pm 0.16$

2nd method, much more precise, needs 3rd quark family, will be discussed later.

Unitarity check of the udsc matrix:

V_{ud}	V_{us}	V_{ub}
V_{cd}	V_{cs}	V_{cb}
V_{td}	V_{ts}	V_{tb}

Inputs:
$|V_{ud}| = 0.9737 \pm 0.0007$
$|V_{us}| = 0.2210 \pm 0.0023$
$|V_{cd}| = 0.224 \pm 0.016$
$|V_{cs}| = 1.04 \pm 0.16$

$\|V_{ud}\|^2 + \|V_{us}\|^2$	$= 0.9969 \pm 0.0017$	$-1.8\ \sigma$
$\|V_{cd}\|^2 + \|V_{cs}\|^2$	$= 1.13 \pm 0.33$	$+0.4\ \sigma$
$\|V_{ud}\|^2 + \|V_{cd}\|^2$	$= 0.9983 \pm 0.0073$	$-0.2\ \sigma$
$\|V_{us}\|^2 + \|V_{cs}\|^2$	$= 1.13 \pm 0.33$	$+0.4\ \sigma$
$\|V_{ud}V_{cd}\| - \|V_{us}V_{cs}\|$	$= -0.012 \pm 0.039$	$0.3\ \sigma$
$\|V_{ud}V_{us}\| - \|V_{cd}V_{cs}\|$	$= -0.018 \pm 0.040$	$0.4\ \sigma$

From this unitarity check we cannot predict a 3rd family. Fit:

$$\lambda_{\text{Wolfenstein}} = 0.2235 \pm 0.0033$$

(S = 1.8)

$$\lambda = 0.2235 \pm 0.0033$$

(± 1.5 %)

V_{ud}	V_{us}	V_{ub}
V_{cd}	V_{cs}	V_{cb}
V_{td}	V_{ts}	V_{tb}

Source: Inclusive and exclusive semileptonic B-meson decays

Inclusive decays:

$$\Gamma(B \to l\nu\ X) = \Gamma(b \to l\nu\ c) + \Gamma(b \to l\nu\ u) + o(\Lambda^2_{QCD}/m_b^2)$$

Primary information:

$\tau(B^0)$	1.534 +- 0.013 ps
$\tau(B^+)$	1.653 +- 0.014 ps

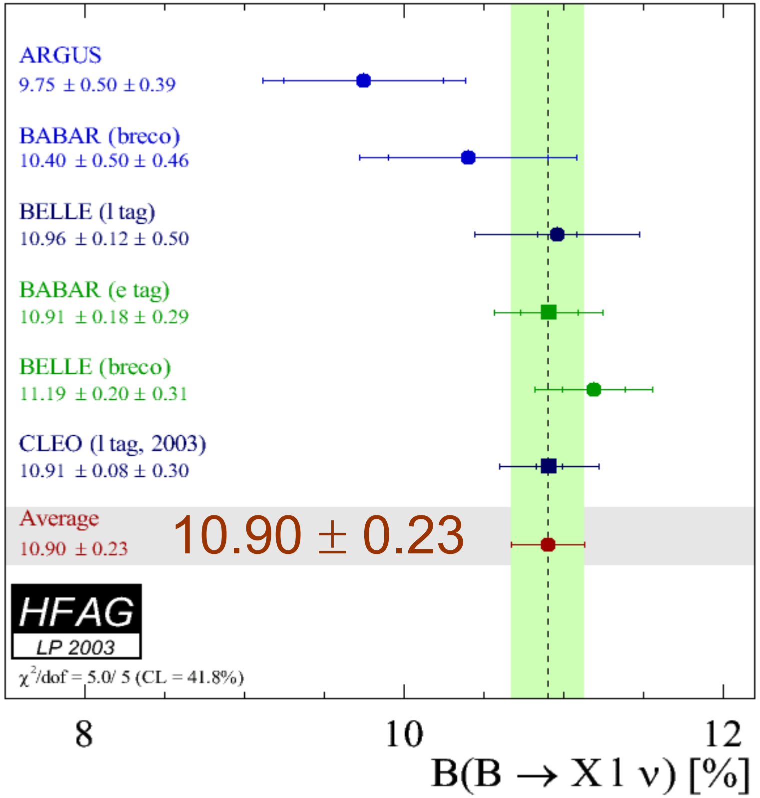
HFAG 07/03

± 0.8%

data from ALEPH, BABAR, BELLE, CDF, DELPHI, L3, OPAL, SLD

$$\Gamma(b \to e\nu\ X) = \frac{BF(b \to e\nu\ X)}{\tau(b)} = \frac{G_F^2 \cdot m_b^5}{192\ \pi^3} \cdot \left(\Phi\left(\frac{m_u}{m_b}\right) \cdot |V_{ub}|^2 + \Phi\left(\frac{m_c}{m_b}\right) \cdot |V_{cb}|^2 \right) + c(\alpha, \alpha_s)$$

Next information: $\boldsymbol{BF}(B \to l\nu\ X)$



$h\,X \rightarrow h\,l^-\,\bar{\nu}Y$

$l^+\nu X$

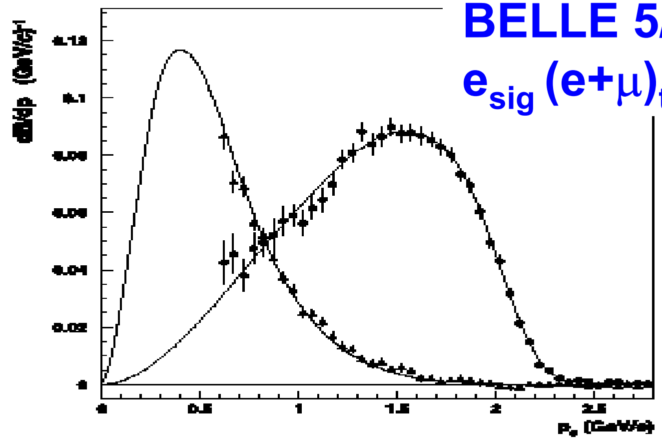
$\uparrow$

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B_{sig}\,\bar{B}_{tag}$

$\downarrow$

Spectrum of $l^-\,\bar{\nu}X$ or $\bar{B}_{reco}$

signal leptons:



Integral over spectrum $\Rightarrow$ ***BF***,

98% $b \rightarrow c$, 2% $b \rightarrow u$, $\sigma_{BF}(V_{cb}) = 1.1\%$, $\sigma_{\tau}(V_{cb}) = 0.4\%$.

1982 spectrum given by ACCMM model, $d\Gamma/dp_l = f(m_b, m_c, p_F, \alpha_s)$.

V_{cb} with $\sigma(V_{cb}) \approx 10\%$. Today QCD, i.e. HQET and OPE:

$m_b \rightarrow \bar{\Lambda}$, $p_F \rightarrow \lambda_1$, $m_c \rightarrow$ substituted, and more parameters λ_2, ρ_i τ_i ...

HQET gives: $$\frac{d^3\Gamma(B\to l\nu\, X_c)}{dm_X^2\, dE_l\, dq^2} = f\left(m_X^2, E_l, q^2 \middle| m_B, |V_{cb}|, \alpha_s, \overline{\Lambda}, \lambda_1, \lambda_2, \ldots\right)$$

No m_c since $$m_B - m_b + \frac{\lambda_1 + 3\lambda_2}{m_b} = \overline{\Lambda} = m_D - m_c + \frac{\lambda_1 + 3\lambda_2}{m_c}$$

Of special interest are the moments M_{ijk} of f. M_{000} :

$$\Gamma(B\to l\nu\, X_c) = \frac{G_F^2\, |V_{cb}|^2}{192\,\pi^3}\cdot 0.369\cdot m_B^5\cdot\left[1 - 1.54\frac{\alpha_s}{\pi} - 1.65\frac{\overline{\Lambda}}{m_B}\left(1 - 0.87\frac{\alpha_s}{\pi}\right) - 0.95\frac{\overline{\Lambda}^2}{m_B^2} - 3.18\frac{\lambda_1}{m_B^2} + 0.02\frac{\lambda_2}{m_B^2} + o\left(\frac{\Lambda_{QCD}}{m_B}\right)^3\right]$$

Bases are duality, HQET, OPE. Local duality predicts results for more low moments like $\langle m_X^2\rangle = M_{100}/M_{000}$, $\langle (m_X^2)^2\rangle = M_{200}/M_{000}$, $\langle E_l\rangle = M_{010}/M_{000}$

Comparing measurements and calculations of „low“ M_{ijk} tests goodness of local duality and expansions, and determines λ_1, $\overline{\Lambda}$, $|V_{cb}|$...

OPE and duality are not valid „too locally“, i.e. „high“ moments and the full $d^3\Gamma$ are not determining λ_1, $\overline{\Lambda}$, $|V_{cb}|$...

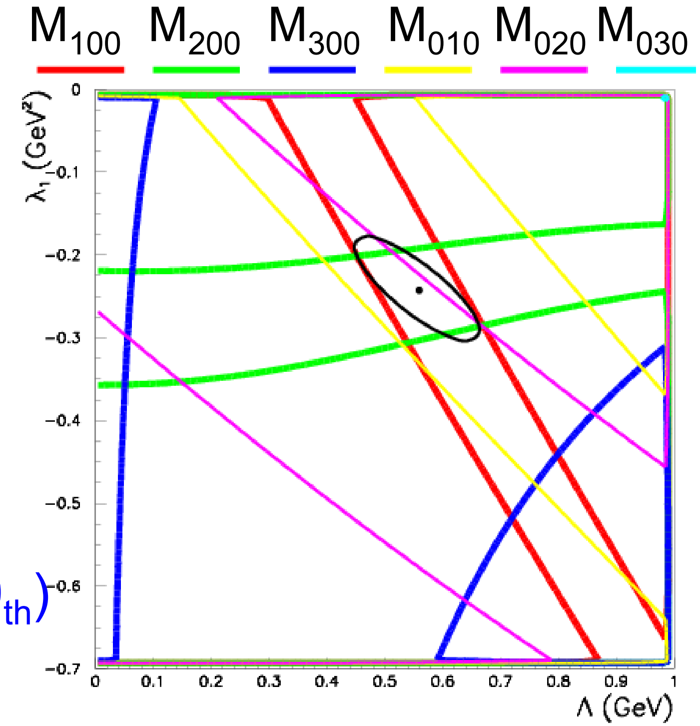
Moment measurements: CLEO, DELPHI, BABAR

DELPHI 2003 determines M_{i00} by reconstructing $B \to D^{**} l\nu$ events from 34 M Z at LEP. $\langle m_X^2 - \overline{m}_D^2 \rangle = (0.647 \pm 0.046 \pm 0.093)\ \mathrm{GeV}^2$, $\overline{m}_D = (m_D + 3 m_{D^*})/4$. Also results for M_{200}, M_{300}

2002 they obtained $\langle E_l \rangle = (1.383 \pm 0.012 \pm 0.009)$ GeV, also M_{020}, M_{030}.

They fit in two mass schemes,
with $\overline{\mathrm{MS}}$ scheme:

Fit Parameter	Fit Values	Fit Uncertainty	Syst. moments	Syst. theory
$\bar{\Lambda}$ (GeV)	0.542	± 0.065	± 0.087	± 0.04
λ_1 (GeV^2)	-0.238	± 0.055	± 0.028	± 0.06



With kinetic scheme:

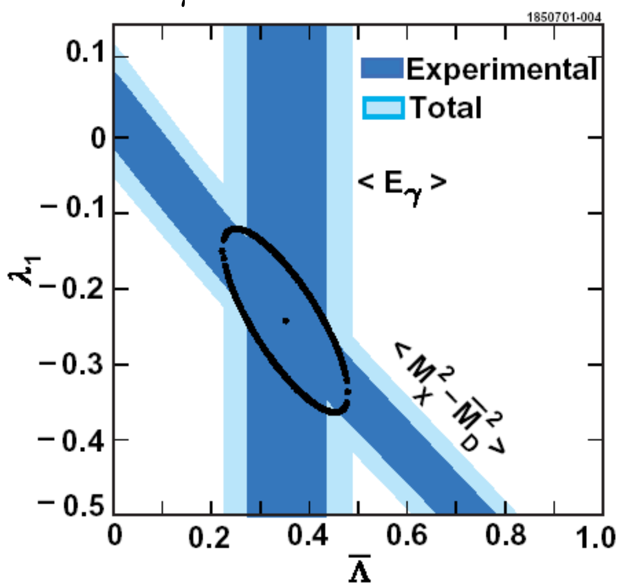
$|V_{cb}| = 0.0429\ (1 \pm 0.012_{\Gamma sl} \pm 0.019_{fit} \pm 0.010_{th})$

BF$(B \to l\nu X)$ readjusted to 10.9%

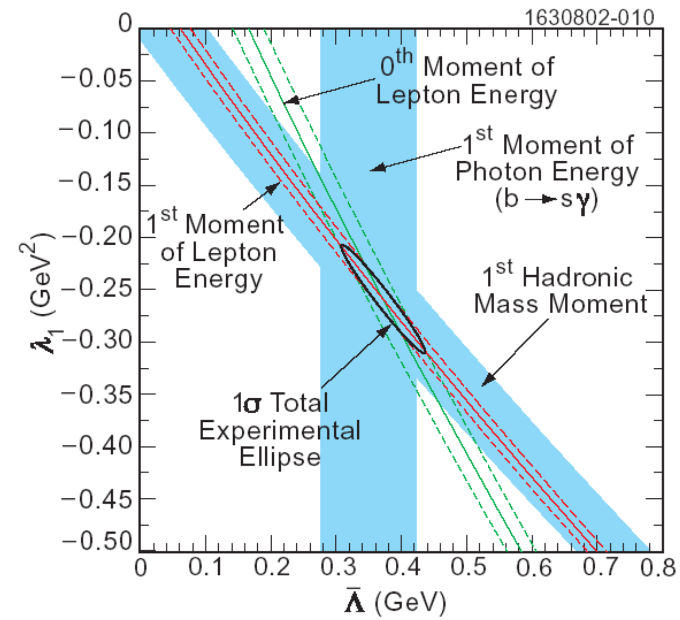
Because of the high B-meson boost, DELPHI moments in full m_x,E_l,q^2 space, $E_l^* \geq 0$. Different for CLEO and BABAR.

CLEO 2001 results:

$<m_X^2 - \overline{m}_D^2>$ (E_l >1.5 GeV) =(0.251±0.023±0.062) GeV^2 and $<E_\gamma>$ from $b \to s\gamma$:



from E_l spectrum, M_{010} (E_l >1.5 GeV) and M_{000} (>1.7 GeV) / M_{000} (>1.5 GeV)



$|V_{cb}|^{(*)} = 0.0414\ (1 \pm 0.012_{\Gamma sl} \pm 0.022_{fit} \pm 0.020_{th})$

$|V_{cb}|^{(*)} = 0.0418\ (1 \pm 0.012_{\Gamma sl} \pm 0.012_{fit} \pm 0.022_{th})$

(*) ***BF***(B → lνX) re-adjusted to 10.9%

No combined fit performed.

BABAR 2003 results:

Moments M_{100} with

E_l > 0.9 ... 1.6 GeV,

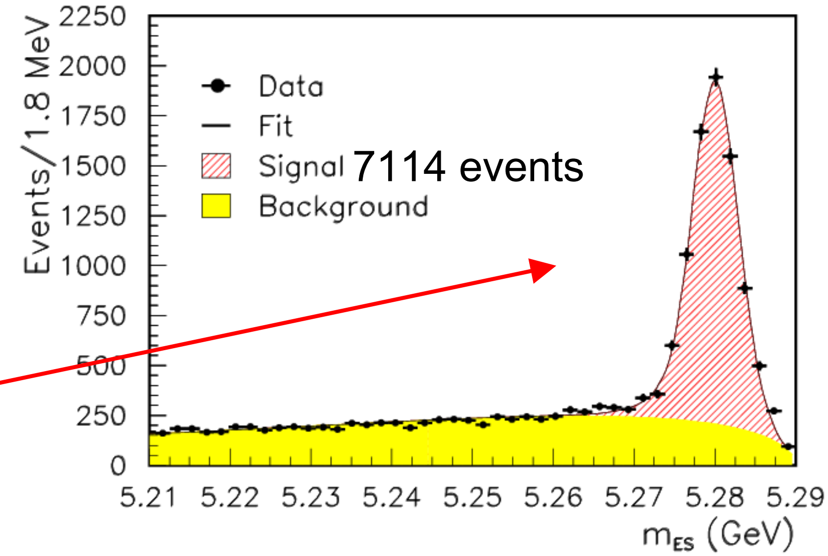
obtained from 89 M $B\bar{B}$

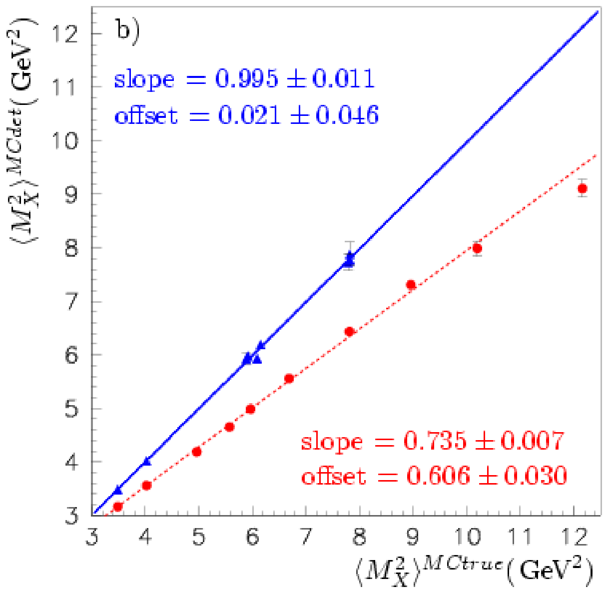
with B_{tag} fully reconstructed,

e and μ in B_{signal}, E_l > 0.9 GeV.

$\tilde{m}_{X,signal}$ from fit to p_{miss} and m_{obs}

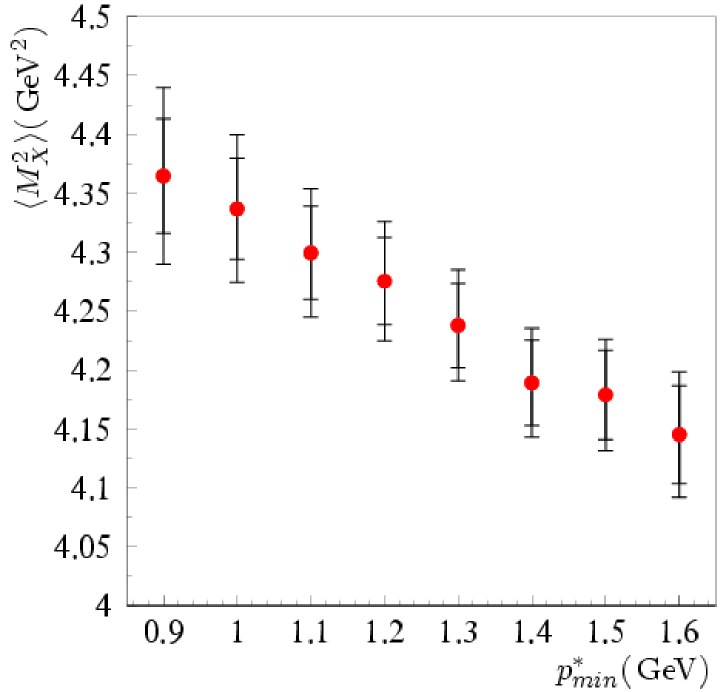
$\langle\tilde{m}_X^2\rangle \rightarrow \langle m_X^2\rangle$ using MC:





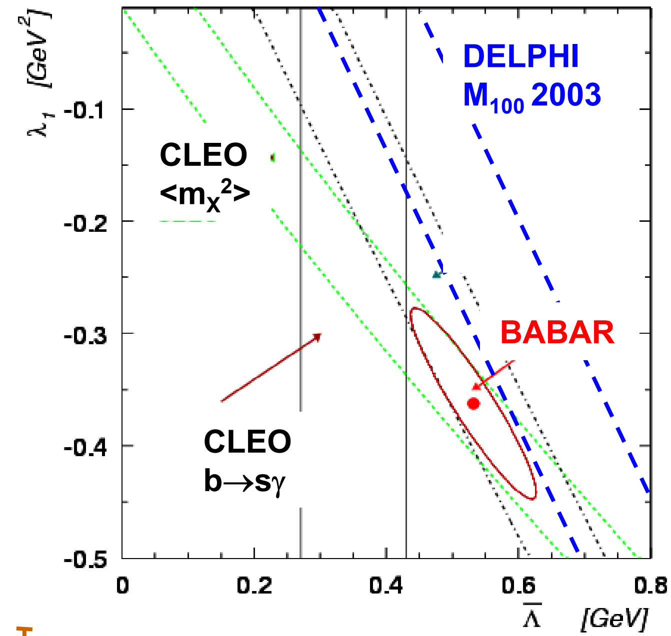
Very small model dependence!

Obtained moments M_{100} :



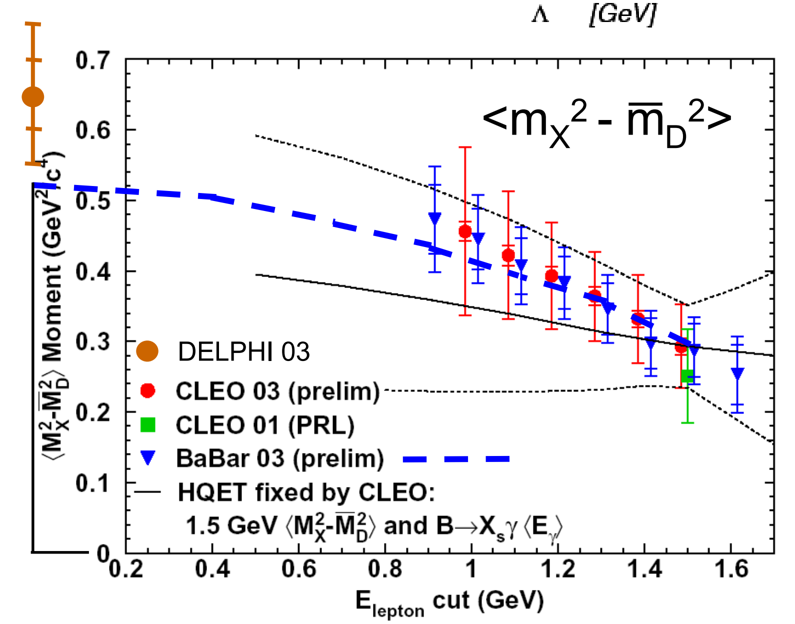
BABAR fits HQET parameters
in 3 schemes, here pole mass ⇒

quotes $|V_{cb}|$ from 1S scheme:
$0.0421(1\pm0.025_{exp}\pm0.017_{th})$



CLEO 2003:

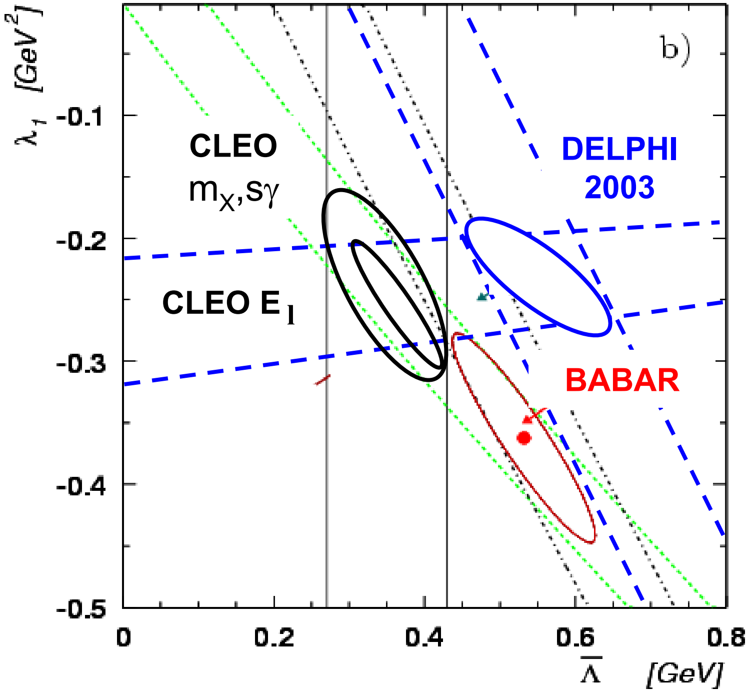
~10 M $B\bar{B}$, $p_{miss} = p_{e+e-} - p_{obs} = p_\nu$
$|M_{miss}^2/2E_\nu| < 0.35$ GeV, only 1 e or μ,
m_X^2, q^2, E_1 for each event,
$<m_X^2>$ from fit in 3 dimensions
to MC sum of $l\nu$ (D,D*,D**,nonres,u)



Result:

No new fit of $\bar{\Lambda}$, λ_1, $|V_{cb}|$.

Summary V_{cb} inclusive:



Moment measurements

of $\dfrac{d^3\Gamma(B \to l\nu\ X_c)}{dm_X^2\ dE_l\ dq^2}$

and HQET/OPE offer the potential to determine $|V_{cb}|$ with $\sigma < 2\%$.

<u>Duties for experiment:</u>

Identify inconsistency areas.

<u>for theory:</u> Identify best scheme (1S ?), get terms with α_s/m_b^2 and more $1/m_b^3$ and α_s^2 terms ...

$|V_{cb}|_{incl} = 0.0429\ (1 \pm 0.012_{\Gamma sl} \pm 0.019_{fit} \pm 0.010_{th})$ DELPHI, kin

$0.0414\ (1 \pm 0.012_{\Gamma sl} \pm 0.022_{fit} \pm 0.020_{th})$ CLEO m, pole mass

$0.0418\ (1 \pm 0.012_{\Gamma sl} \pm 0.012_{fit} \pm 0.022_{th})$ CLEO E, pole mass

$0.0421\ (1 \pm 0.025_{exp} \pm 0.017_{th})$ BABAR, 1S

My average: $|V_{cb}|_{incl} = 0.0421 \pm 0.0013\ \ (3.0\%)$

Exclusive V_{cb} determination: from $\frac{d\Gamma(B^0 \to D^{*-}\ell\nu)}{dw}$; $w = \frac{m_{D^*}^2 + m_D^2 - q^2}{2 m_{D^*} m_D}$

new results submitted to LP03 by DELPHI and BABAR

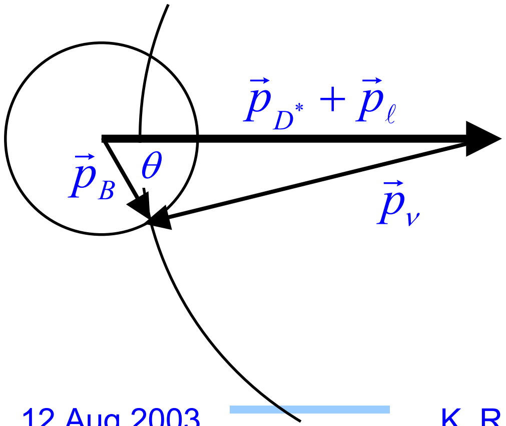
both with full reconstruction $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+, K^-\pi^+\pi^+\pi^-, K^-\pi^+\pi^0$

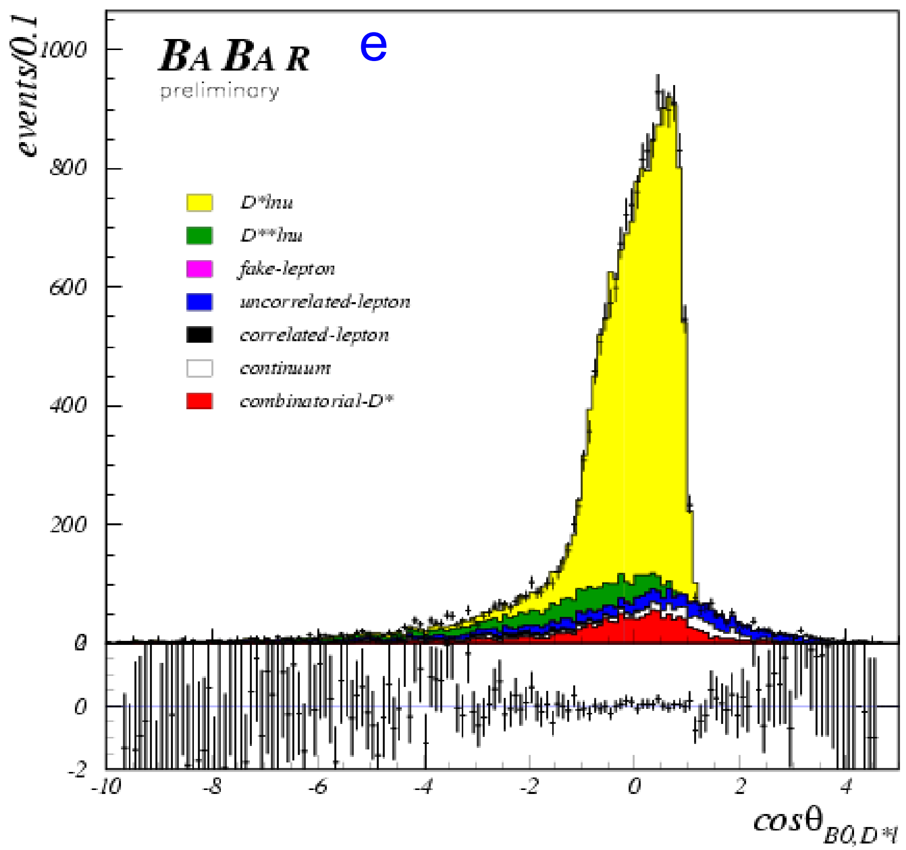
DELPHI 3.4 M Z, 1688 ev. (e+μ), BABAR 86 M Υ(4S), 55700 (e+μ)

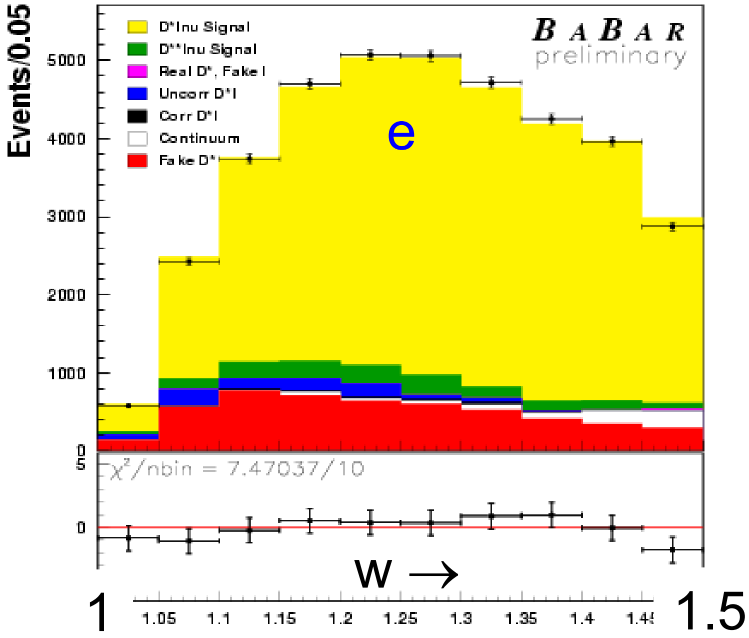
Delicate background from D**.

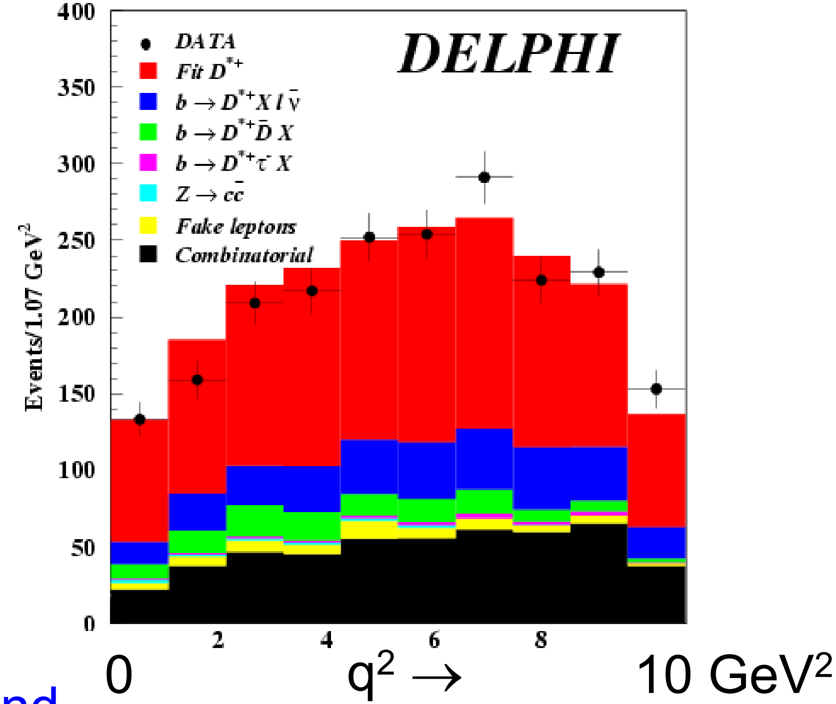
DELPHI uses hemisphere and vertex separation to identify extra tracks from B_{sig}

BABAR uses cos θ_{B,D^*l}









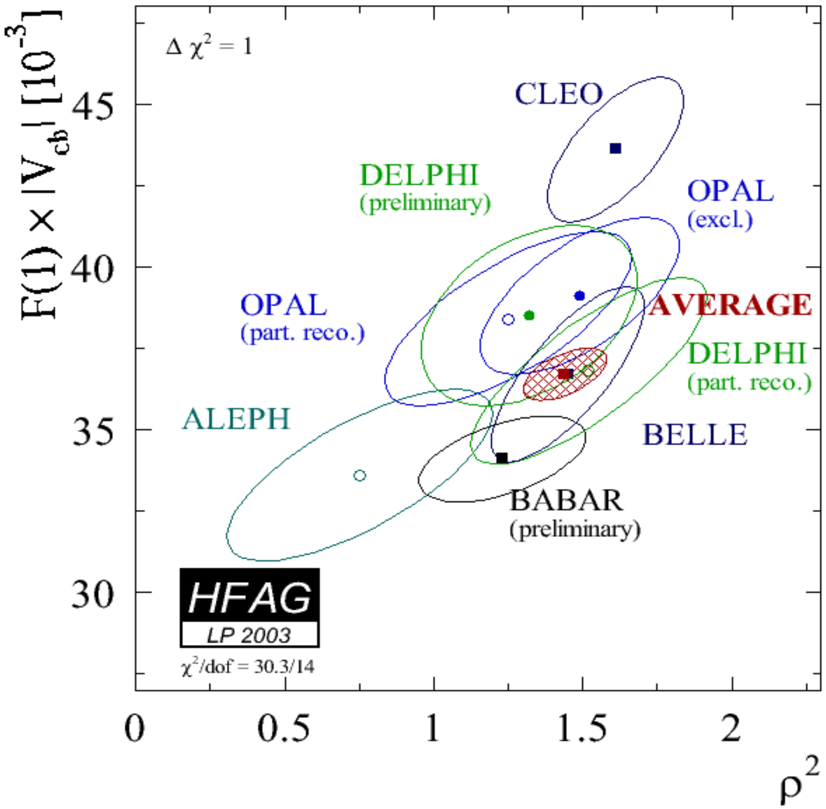
Advantage of BABAR: less background,

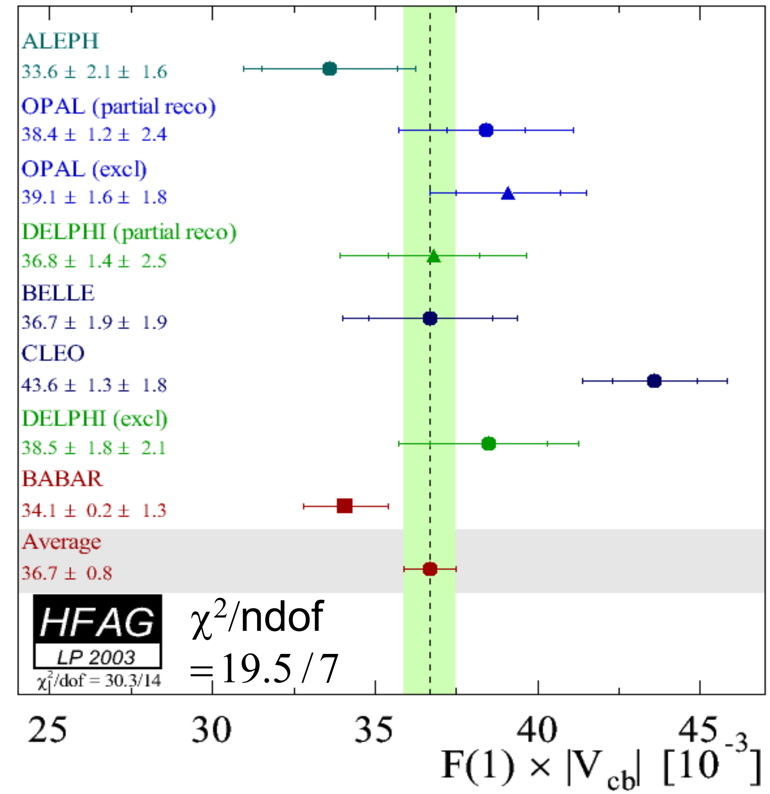
of DELPHI: large acceptance also at q^2_{max}, i.e. w = 1. <u>Results:</u>

	DELPHI	BABAR
$10^3\|V_{cb}\|\cdot F(1)$	39.2±1.8±2.2	34.0±0.2±1.3
ρ_{A1}^2	1.32±0.15±0.33	1.23±0.02±0.28
BF$(B^0 \to D^* l \nu)$%	5.90±0.22±0.48	4.68±0.03±0.29

~2 σ discrepancy

Summary for V_{cb}:





$|V_{cb}| \cdot F(1) = 0.0367 \pm 0.0013$ (S = 1.7)

$F(1) = 0.913 \,{}^{+0.030}_{-0.035}$ HQET

$|V_{cb}|_{incl} = 0.0421 \pm 0.0013$

$|V_{cb}|_{excl} = 0.0402 \pm 0.0020$

$|V_{cb}| = 0.0415 \pm 0.0011$

$$A\lambda^2 = 0.0415 \pm 0.0011$$

$(\pm 2.7\ \%)$

$$\begin{matrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{matrix}$$

Source: Inclusive and exclusive semileptonic B-meson decays into charmless final states

Exclusive decays:

BELLE: ***BF*** for $B^0 \to \pi^- l\nu$, $B^+ \to \rho^0 l\nu$, $B^+ \to \omega l\nu$, no $|V_{ub}|$

BABAR: $|V_{ub}|$ from $B^0 \to \rho^- e^+\nu$, $B^+ \to \rho^0 e^+\nu$
with 55 M Υ(4S) and 5 form-factor calculations, „model dependent“

CLEO: $|V_{ub}|$ from $\pi^- l^+\nu$, $\pi^0 l^+\nu$, $\eta l^+\nu$, $\rho^- l^+\nu$, $\rho^0 l^+\nu$, $\omega l^+\nu$
with 10 M Υ(4S) and QCD form-factors only, „model independent“

Because of small statistics, both use isospin / quark-model constraints:

$$\Gamma(\rho^o \ell \nu) = \Gamma(\omega \ell \nu) = \Gamma(\rho^- \ell \nu)/2 \,, \Gamma(\pi^o \ell \nu) = \Gamma(\pi^- \ell \nu)/2$$

BABAR 2003:

$B^0 \to \rho^- e^+ \nu$

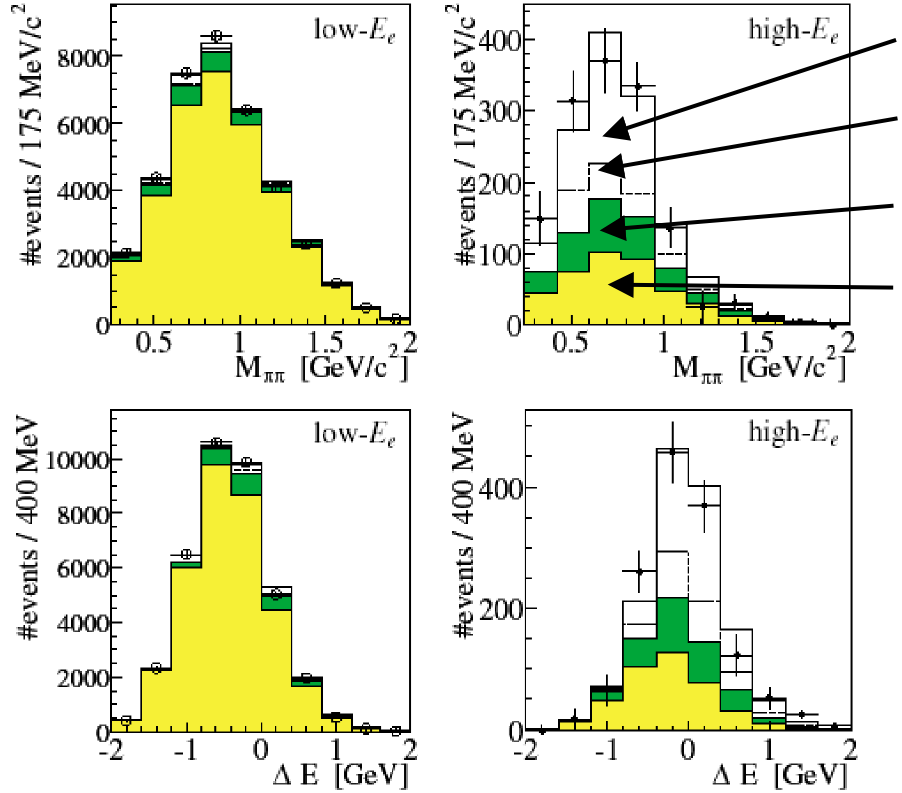
$B^+ \to \rho^0 e^+ \nu$

high - E_l: 2.3-2.7 GeV

low - E_l: 2.0-2.3 GeV

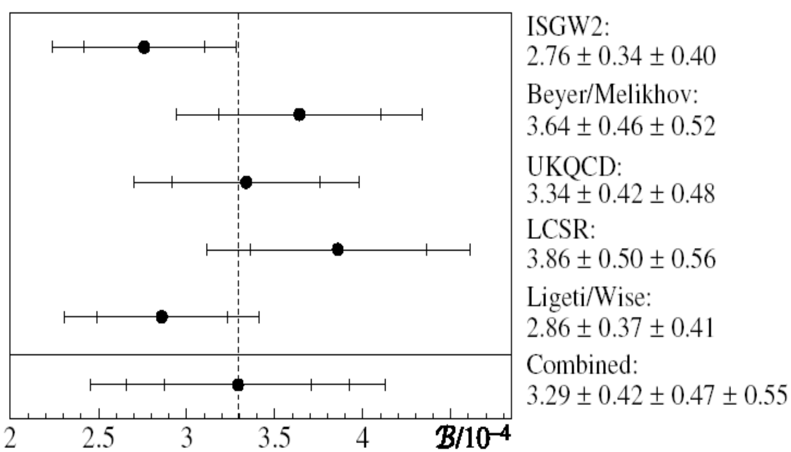
signals for ρ^- ⇒

results from ρ^- & ρ^0 ⇓

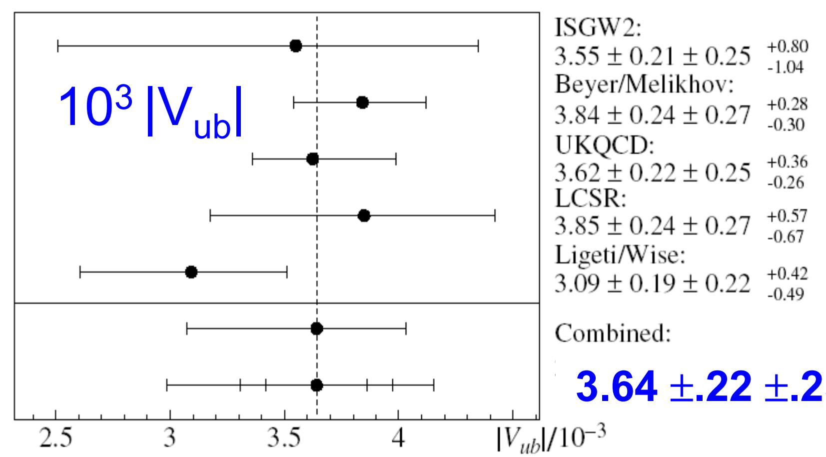


continuum is already subtracted

10^4 $\mathcal{BF}(B^0 \to \rho^- e^+ \nu)$

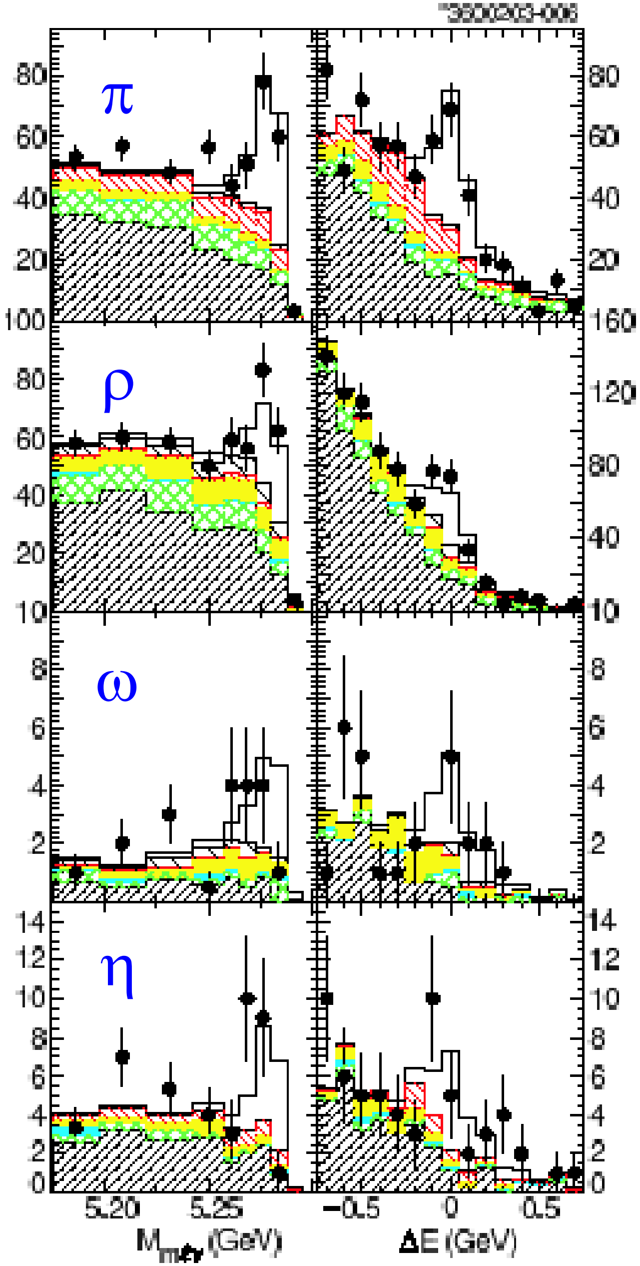


10^3 $|V_{ub}|$



$3.64 \pm .22 \pm .25^{+.39}_{-.56}$

CLEO 2003:

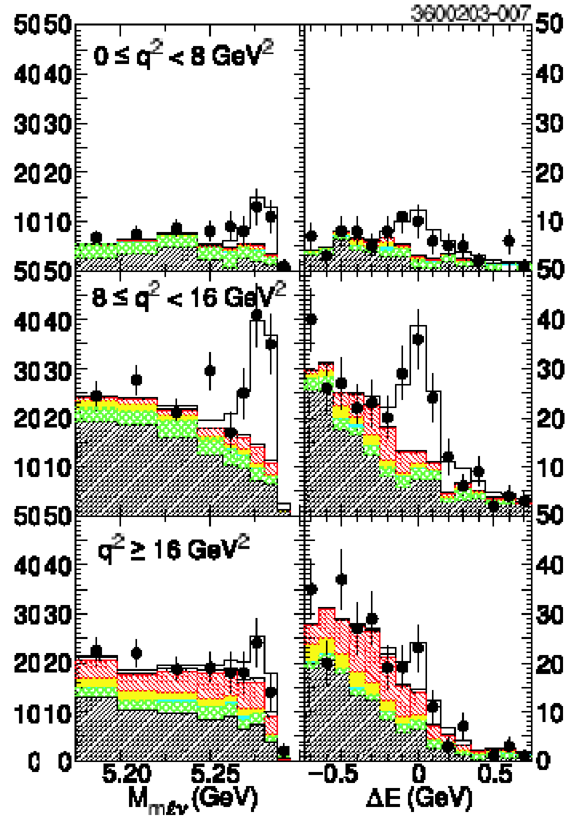


Detector hermeticity ⇒ „ν reconstruction“

⇒ q^2 and E_l >1.0 GeV (π), >1.5 GeV (ρ)

⇐ Signals

in q^2 bins ⇓



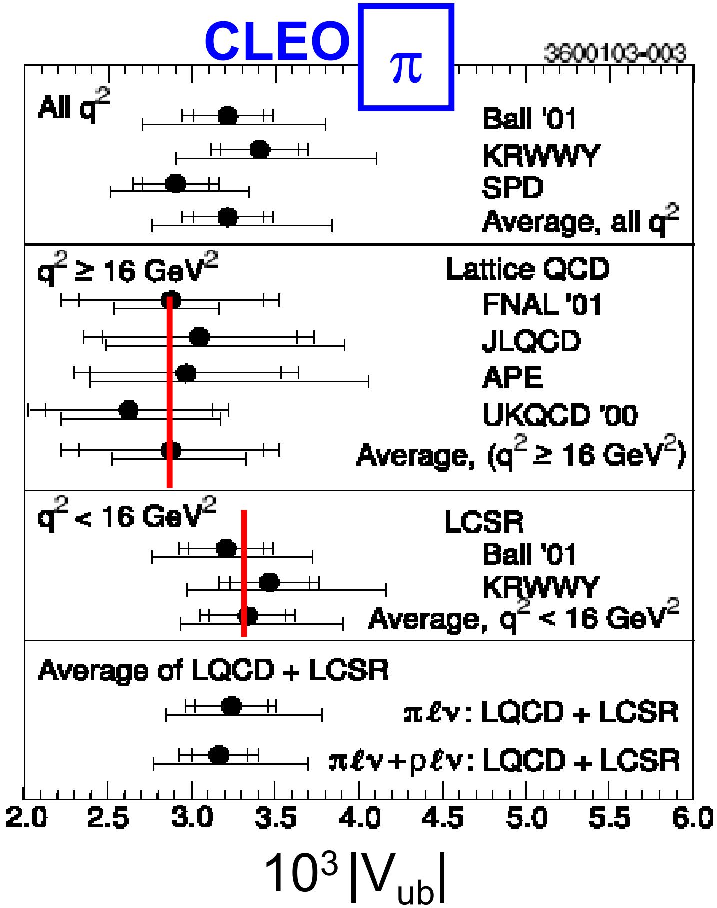
white = signal

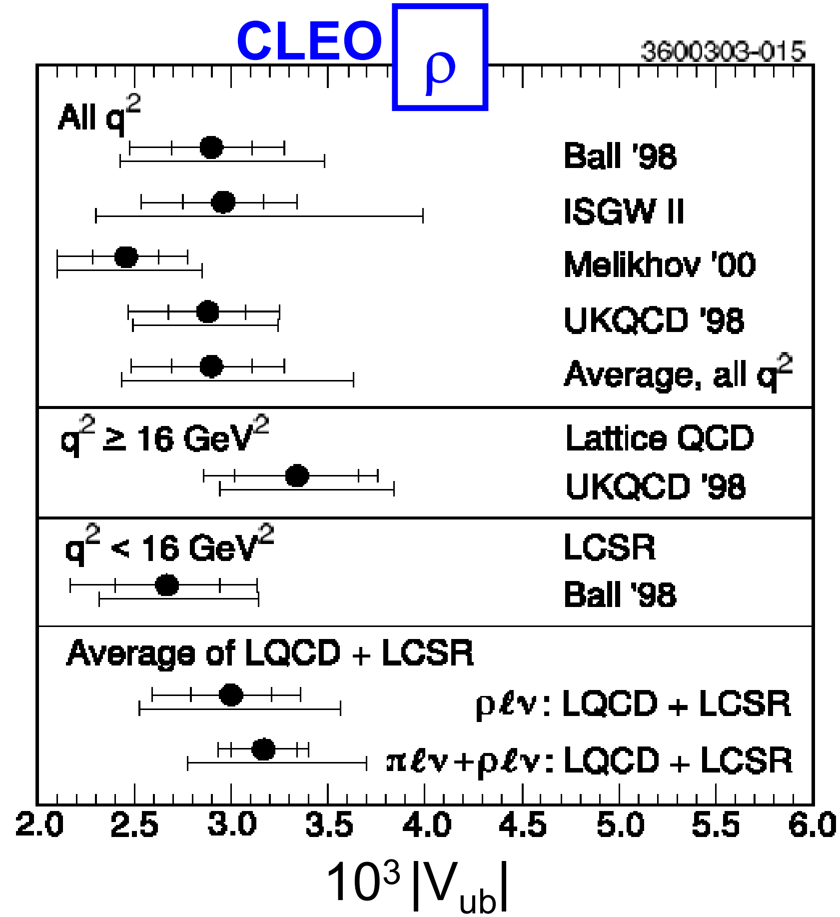
red = crossfeed

yellow = downfeed

green = continuum

black = b→clν



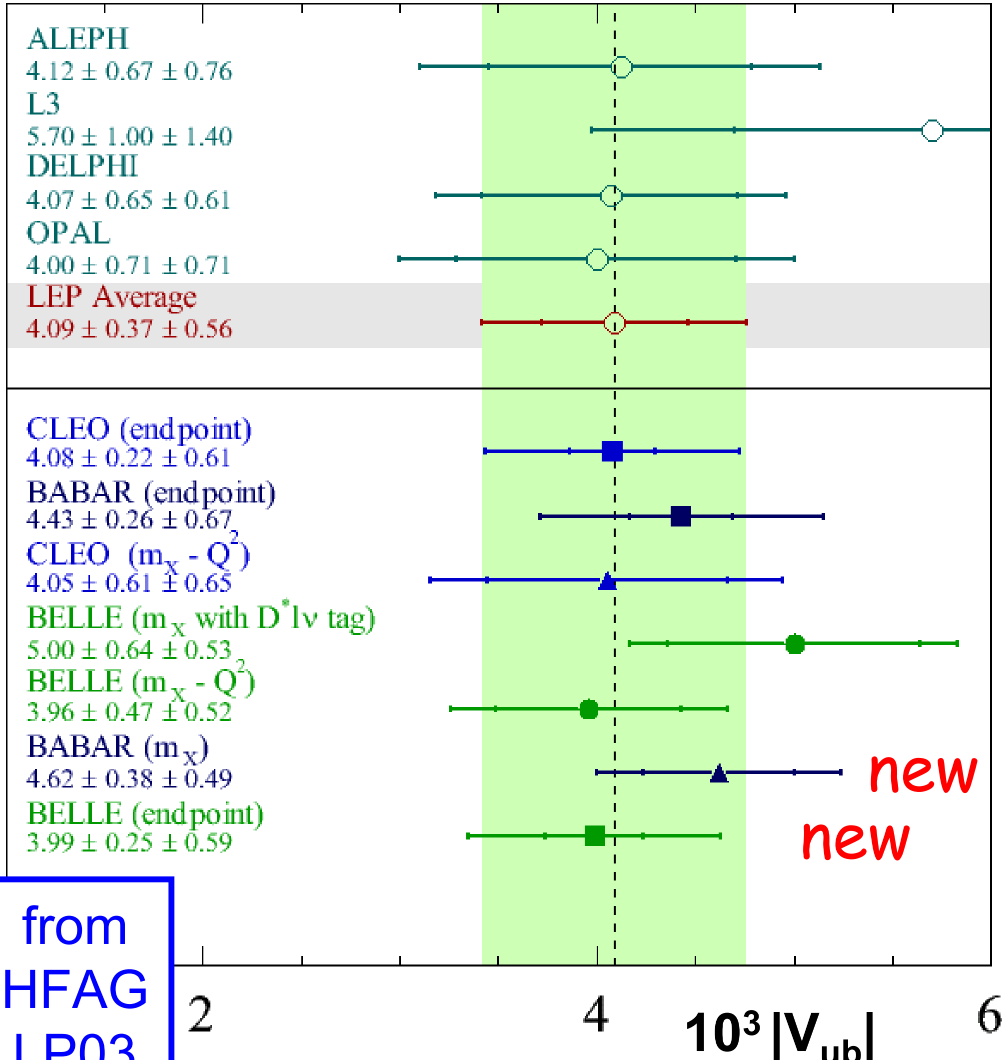


$$|V_{ub}|_{CLEO,\pi+\rho} = (3.17 \pm 0.17\ {}^{+0.16}_{-0.17}\ {}^{+0.53}_{-0.39})\ 10^{-3}$$

$$|V_{ub}|_{BABAR,\rho} = (3.64 \pm 0.22 \pm 0.25\ {}^{+0.39}_{-0.56})\ 10^{-3}$$

$$|V_{ub}|_{excl} = (3.40\ {}^{+0.24}_{-0.33} \pm 0.40)\ 10^{-3}$$

Inclusive decays $b \to ul\nu$:



from HFAG LP03

Three methods

1) $E_l > 2.3$ GeV, „endpoint“

2) $E_l > 1.0$ GeV
and $m_X < 1.5$ GeV,
requires tagged B,
less QCD-dependent.

3) $E_l > 1.0$ GeV
and $m_X < 1.5$ GeV
and $q^2 > 12$ GeV^2,
requires tagged B
and high statistics.
needs even less QCD.

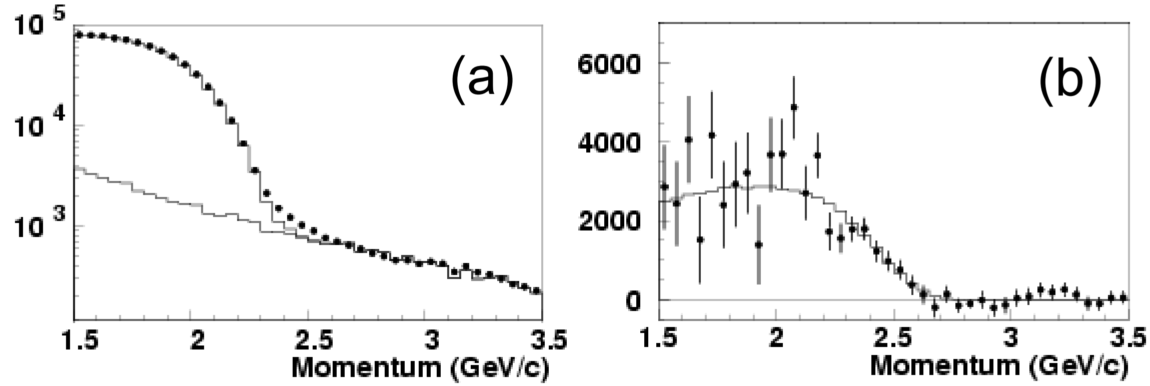
BELLE:

29 MΥ(4S),

(a) B→eνX

(b) continuum

and b→c subtracted



$\boldsymbol{BF}$ (B →eνX$_u$) = Δ$\boldsymbol{BF}$ (2.3 < E$_l$ < 2.6 GeV) / f$_u$(CLEO)

$|V_{ub}| = (3.99 \pm 0.17_{stat} \pm 0.16_{sys} \pm 0.59_{th})\, 10^{-3}$

What is f$_u$? Already used in endpoint analyses of CLEO and BABAR.

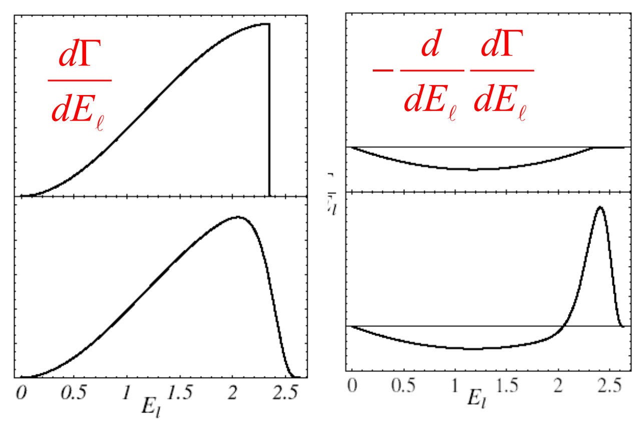
Determined by shape function, also concept of HQET,

but beyond OPE, needs nonlocal operators („twists“).

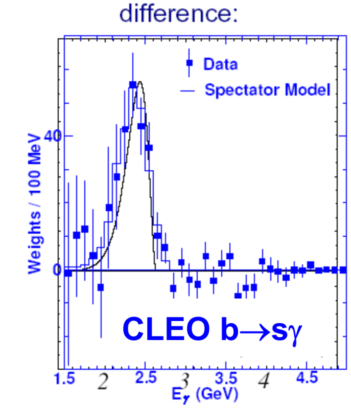
From Z. Ligeti
FPCP-03 Paris:

b-quark decay

B-meson decay



difference:

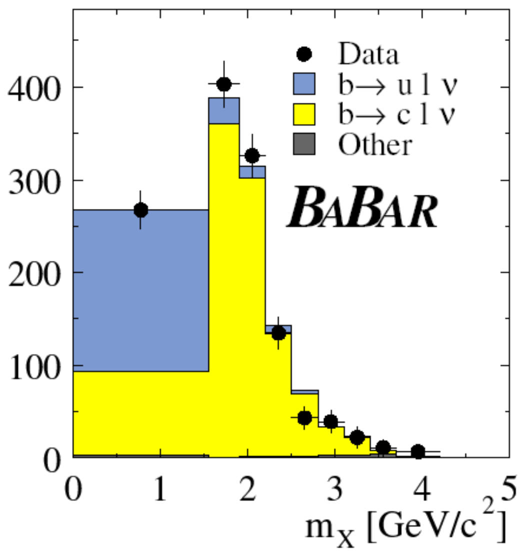


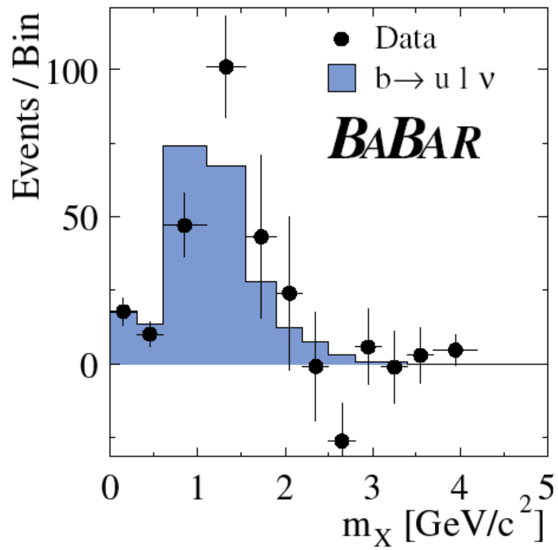
m_X Result of BABAR:

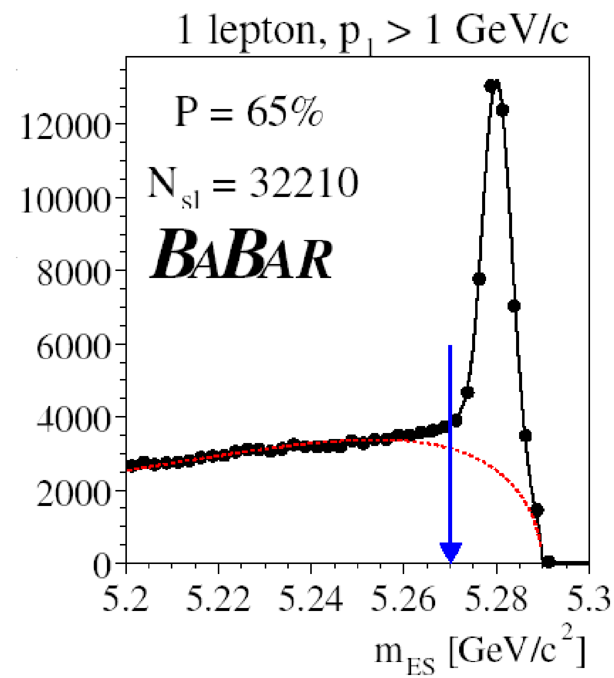
89 MΥ(4S), 32 k events with

$\Upsilon(4S) \rightarrow B_{reco}B_{sig}$, E_l >1 GeV, B_{reco} $\Rightarrow$

reconstruct m_X in $B_{sig} \rightarrow l\nu X$ $\Downarrow$





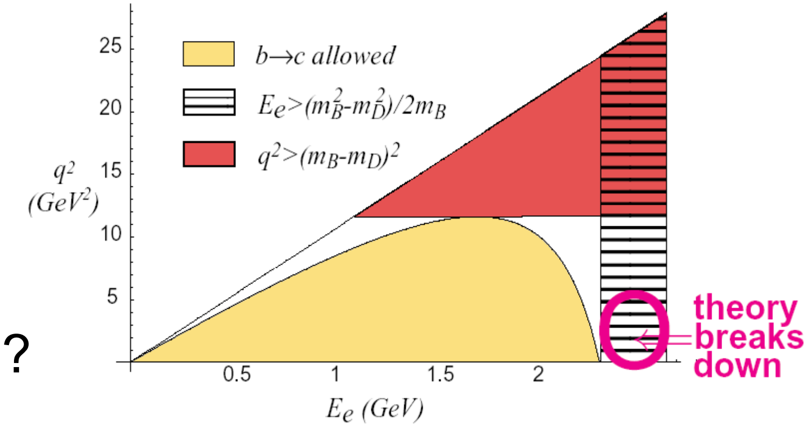


Using the shape function $\Rightarrow$

$$|V_{ub}| = (4.62 \pm 0.28_{stat} \pm 0.27_{sys} \pm 0.40_{shf} \pm 0.26_{\Gamma\rightarrow Vub})\ 10^{-3}$$

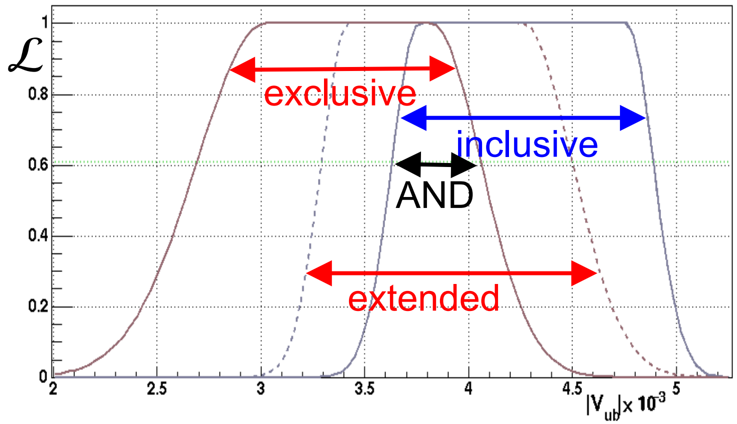
Summary for $V_{ub,incl}$:

No discussion of m_X-q^2 method here.
Best prospects in the future because of smallest dependence on HQET parameters. Take them from V_{cb} data?



HFAG does not yet present an average for $|V_{ub}|_{incl}$.

My weighted inclusive mean: $|V_{ub}|_{incl} = (4.26 \pm 0.13 \pm 0.50)\, 10^{-3}$



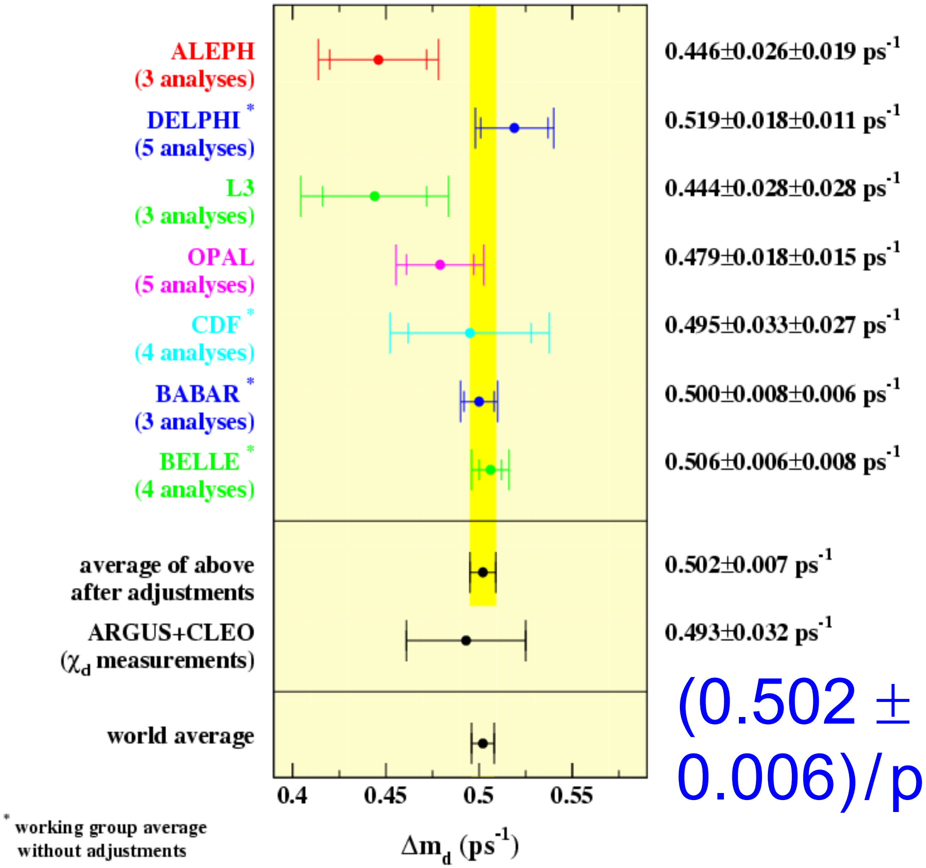
$$|V_{ub}|_{excl} = (3.40\ {}^{+0.24}_{-0.33} \pm 0.40)\, 10^{-3}$$

$$|V_{ub}| = (3.80\ {}^{+0.24}_{-0.13} \pm 0.45)\, 10^{-3}$$

V_{ud}	V_{us}	V_{ub}
V_{cd}	V_{cs}	V_{cb}
V_{td}	V_{ts}	V_{tb}

Source: Δm_d of $B^0\bar{B}^0$ Oscillations

from HFAG LP03 ⇒



(0.502 ± 0.006)/ps

$$\Delta m_d = \frac{G_F^2\, m_{B_d} f_{B_d}^2 B_{B_d} \eta_B}{6\pi^2} \cdot |V_{td}|^2 \cdot |V_{tb}|^2 \cdot f(m_t^2, m_W^2)$$

$f_B^2 B_B = (223 \pm 33 \pm 12)^2$ MeV^2 from lattice QCD

$|V_{td}| \cdot |V_{tb}| = (9.2 \pm 1.4 \pm 0.5)\ 10^{-3}$

$$\begin{matrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{matrix}$$

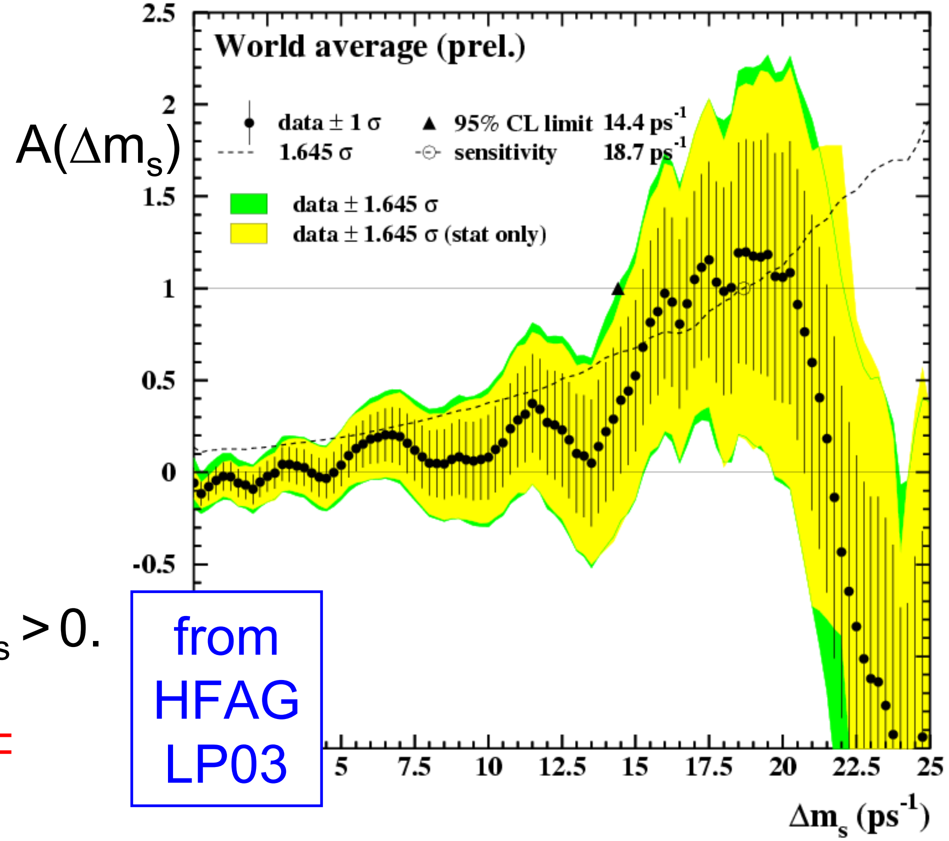
from $B_s\bar{B}_s$ oscillations

and $b \to s\gamma$ penguins

$\Delta m_s > 0$ since $\chi_s = (\chi - f_d\chi_d)/f_s > 0$.

$\Delta m_s >$ 14.4/ps (95% CL) $\Leftarrow$

from HFAG LP03



$$\Delta m_s = \frac{G_F^2 m_{B_s} f_{B_s}^2 B_{B_s} \eta_{B_s}}{6\pi^2} \cdot |V_{ts}|^2 \cdot |V_{tb}|^2 \cdot f(m_t^2, m_W^2)$$

$$\xi = \frac{f_{B_s}\sqrt{B_{B_s}}}{f_{B_d}\sqrt{B_{B_d}}} = 1.24 \pm 0.04 \pm 0.06$$

$|V_{ts}| \cdot |V_{tb}| > 0.033$

Penguins: ***BF*** ($B \to X_s\gamma$) from CLEO, ALEPH, BABAR, BELLE

Ali and Misiak: $|V_{ts}| \cdot |V_{tb}| = 0.047 \pm 0.008$

$$\begin{matrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & \text{again} \\ V_{td} & V_{ts} & V_{tb} \end{matrix}$$

was 1.04 ± 0.16

using $\Gamma(D \to \bar{K} e \nu)$

Decays of real W-bosons at LEP-2 increase precision:

$$\frac{\Gamma(W \to hadrons)}{\Gamma(W \to e\nu)} \propto \frac{|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 + |V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2}{1} = 2.039 \pm 0.026$$

only using that there are five quarks with m(q) < m(W) ⇒

$$|V_{cs}| = 0.995 \pm 0.014$$

<u>Prospects:</u> Check by CLEO-c

Unitarity check of the full CKM matrix:

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \end{pmatrix}$$

$|V_{ud}| = 0.9737 \pm 0.0007$ $|V_{ub}| = 0.0038 \pm 0.0005$

$|V_{us}| = 0.2210 \pm 0.0023$ $|V_{cb}| = 0.0415 \pm 0.0011$

$|V_{cd}| = 0.224 \pm 0.016$ $|V_{cs}| = 0.995 \pm 0.014$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9969 \pm 0.0017 \quad -1.8\,\sigma$$

$$|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 = 1.042 \pm 0.029 \quad +1.5\,\sigma$$

$$|V_{ud}V_{cd}| - |V_{us}V_{cs}| \pm |V_{ub}V_{cb}| = -0.002 \pm 0.016 \quad 0.1\,\sigma$$

The observed CKM matrix magnitudes fulfill unitarity reasonably well.

⇔ All processes which we call „weak“ can be described by the Standard weak interaction in which the CKM matrix is necessarily unitary.

Assuming Unitarity :

$$|V_{tb}|^2 = 1 - |V_{cb}|^2 - |V_{ub}|^2 \quad \Rightarrow \quad |V_{tb}| = 0.99913 \pm 0.00009$$

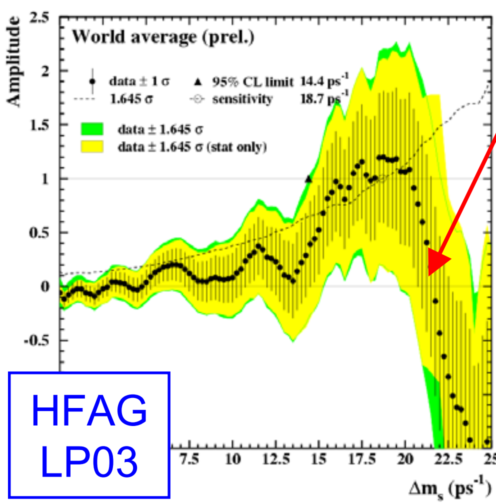
$$|V_{td}| = (9.2 \pm 1.4 \pm 0.5)\ 10^{-3}$$

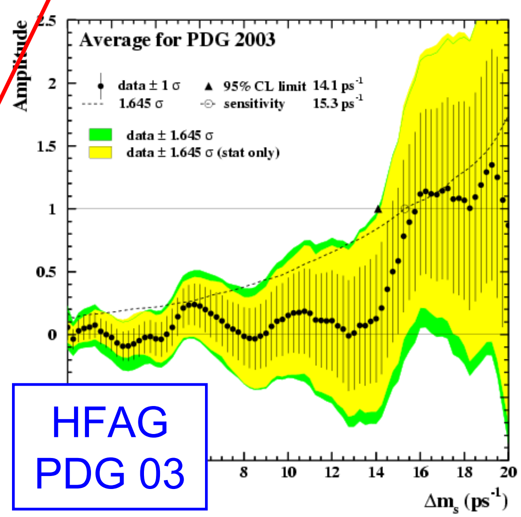
$$|V_{ts}|^2 = |V_{cb}|^2 + |V_{ub}|^2 - |V_{td}|^2 \quad \Rightarrow \quad |V_{ts}| = 0.0406 \pm 0.0023$$

$$\begin{matrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & & \end{matrix}$$

V_{td} again

This region has often been over-interpreted. Better: Measure Δm_s !





$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_d}}{m_{B_s}} \cdot \frac{|V_{td}|^2}{|V_{ts}|^2} \cdot \xi^2$$

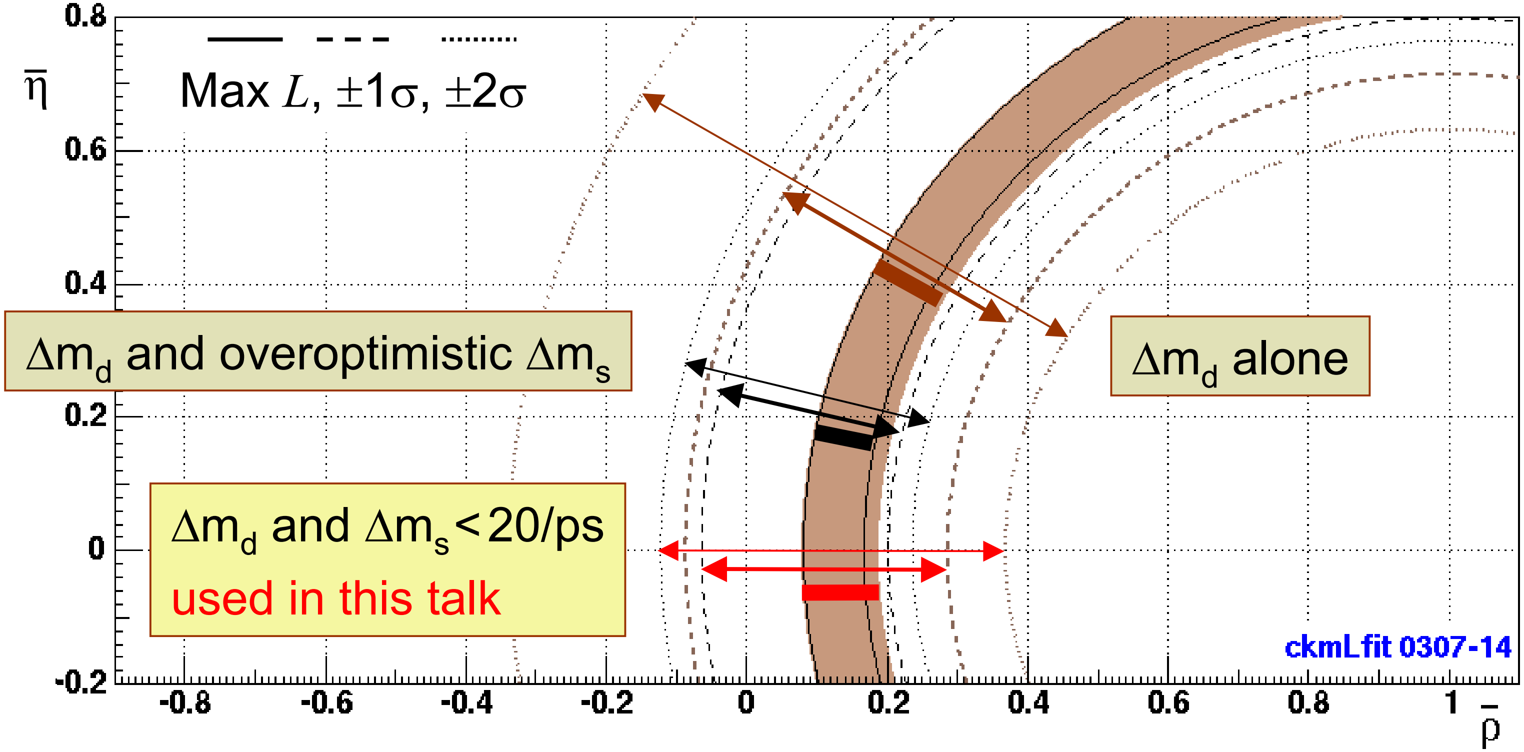
$$\xi = \frac{f_{B_s}\sqrt{B_{B_s}}}{f_{B_d}\sqrt{B_{B_d}}} = 1.24 \pm 0.04 \pm 0.06$$

$$L(\Delta m_s) = \begin{cases} e^{-(A-1)^2/2\sigma_A^2} & |\ \Delta m_s < 20/ps \\ 1 & |\ \Delta m_s > 20/ps \end{cases}$$

Contours for $|V_{td}|$ in the $\bar{\rho}$ - $\bar{\eta}$ plane:

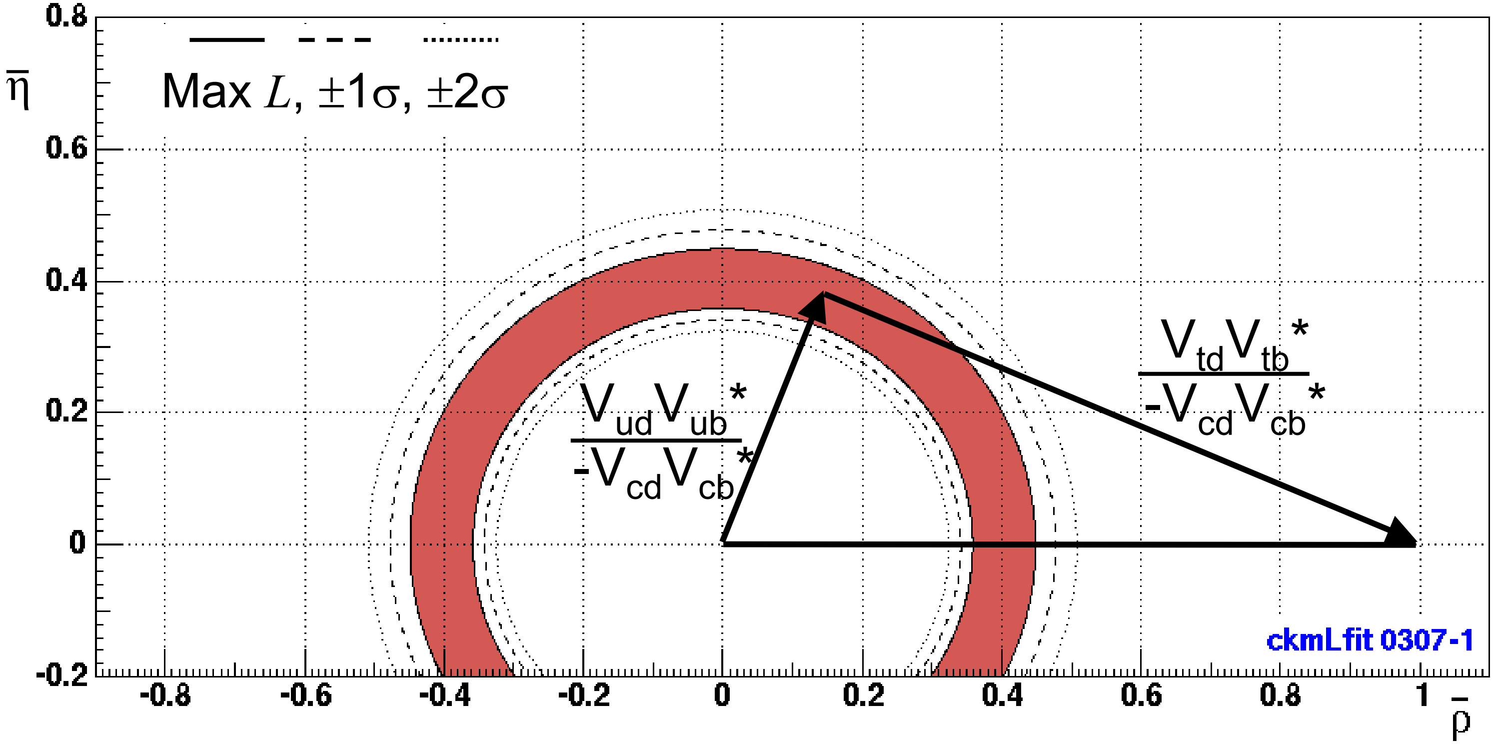
ckm
Lfit

$|V_{td}|$:


Max L, $\pm1\sigma$, $\pm2\sigma$
$\bar{\eta}$
$\bar{\rho}$
0.8
0.6
0.4
0.2
0
-0.2
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Δm_d and overoptimistic Δm_s
Δm_d alone
Δm_d and Δm_s<20/ps
used in this talk
ckmLfit 0307-14

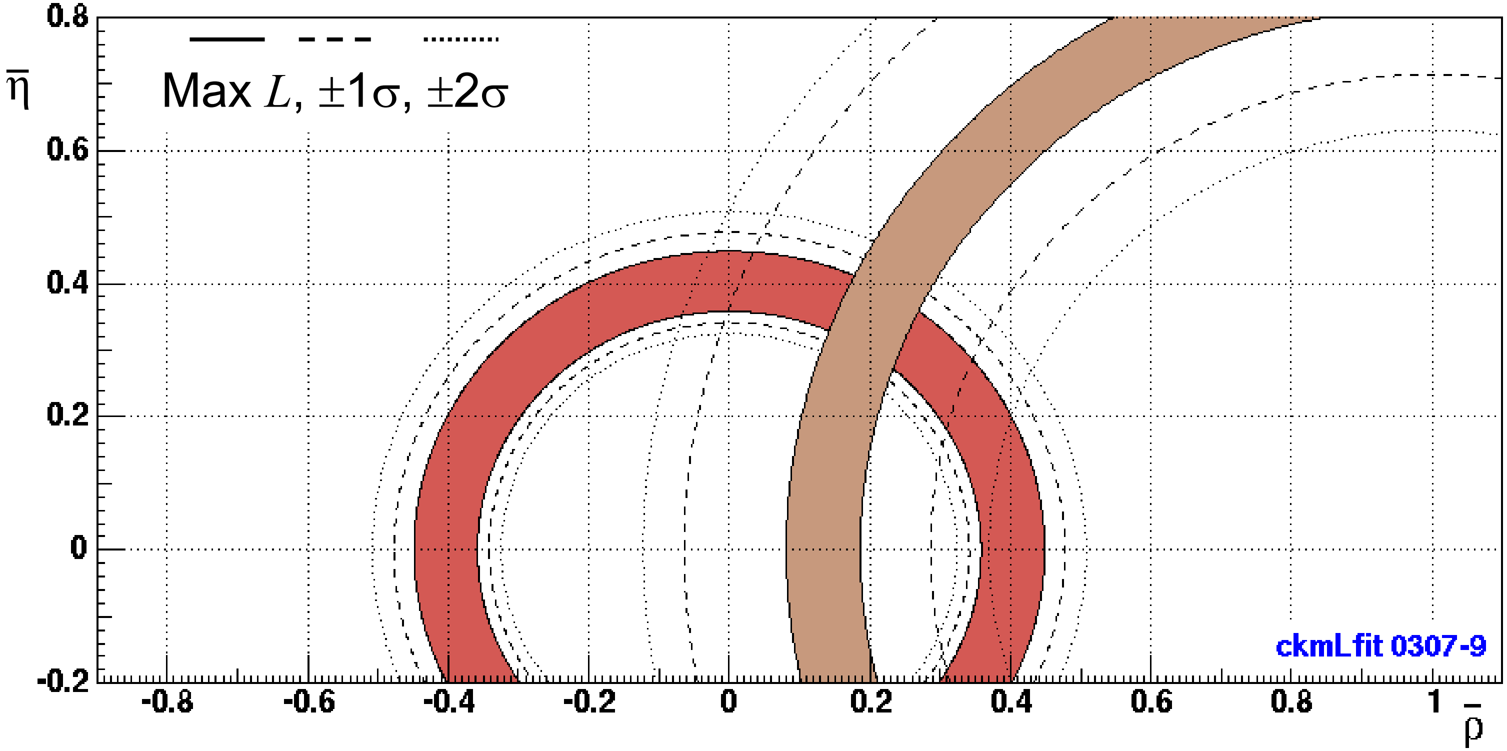
ckm Lfit

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



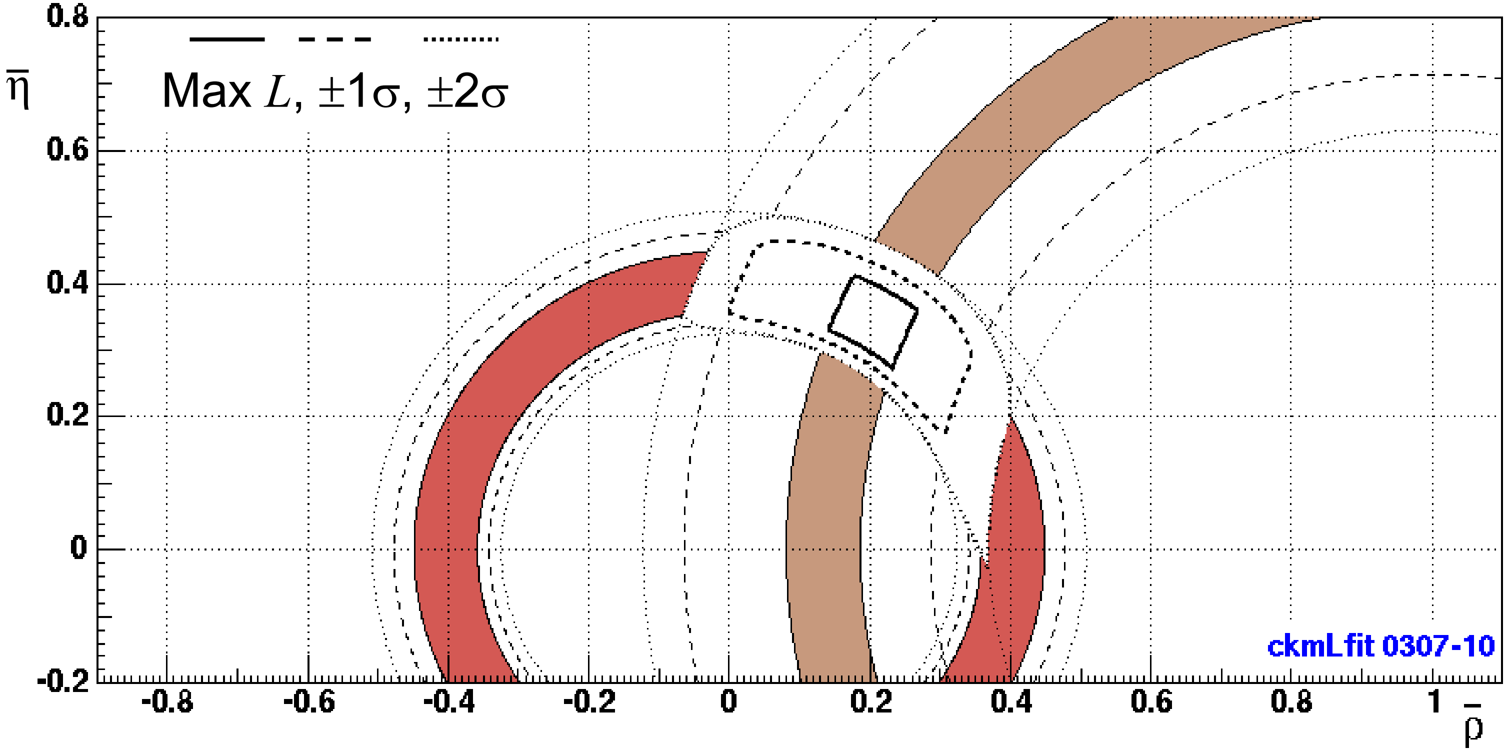
$$\bar{\rho} = \mathrm{Re}\frac{V_{ud}V_{ub}^{*}}{-V_{cd}V_{cb}^{*}}, \quad \bar{\eta} = \mathrm{Im}\frac{V_{ud}V_{ub}^{*}}{-V_{cd}V_{cb}^{*}}$$

ckm
Lfit



Max L, ±1σ, ±2σ
$\bar{\eta}$
0.8
0.6
0.4
0.2
0
-0.2
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
$\bar{\rho}$
ckmLfit 0307-9

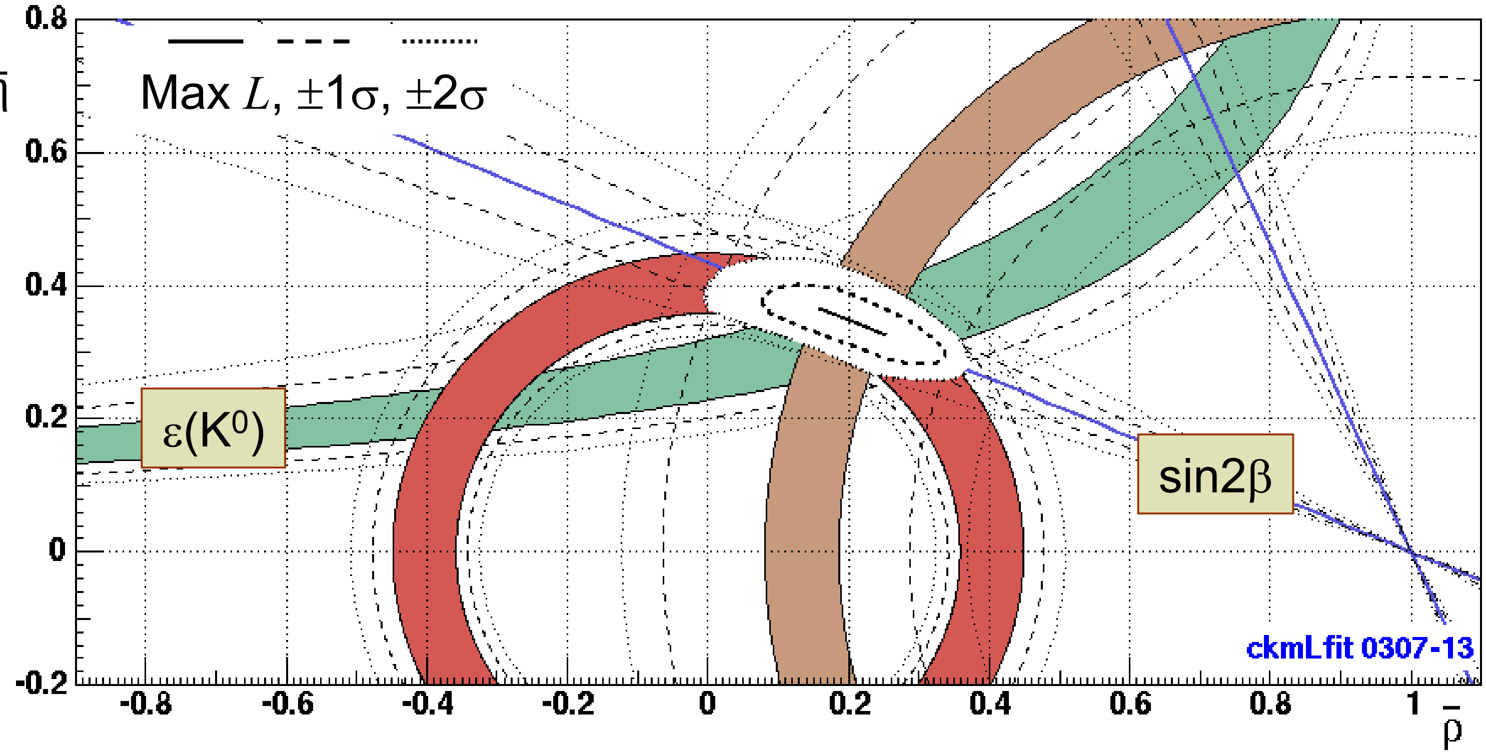
ckm
Lfit



From magnitudes alone: <u>There is CP violation in the St. Model;</u>
but the point $(\bar{\rho},\bar{\eta}) = (0.37, 0)$ is only excluded with 2σ.

ckm
Lfit

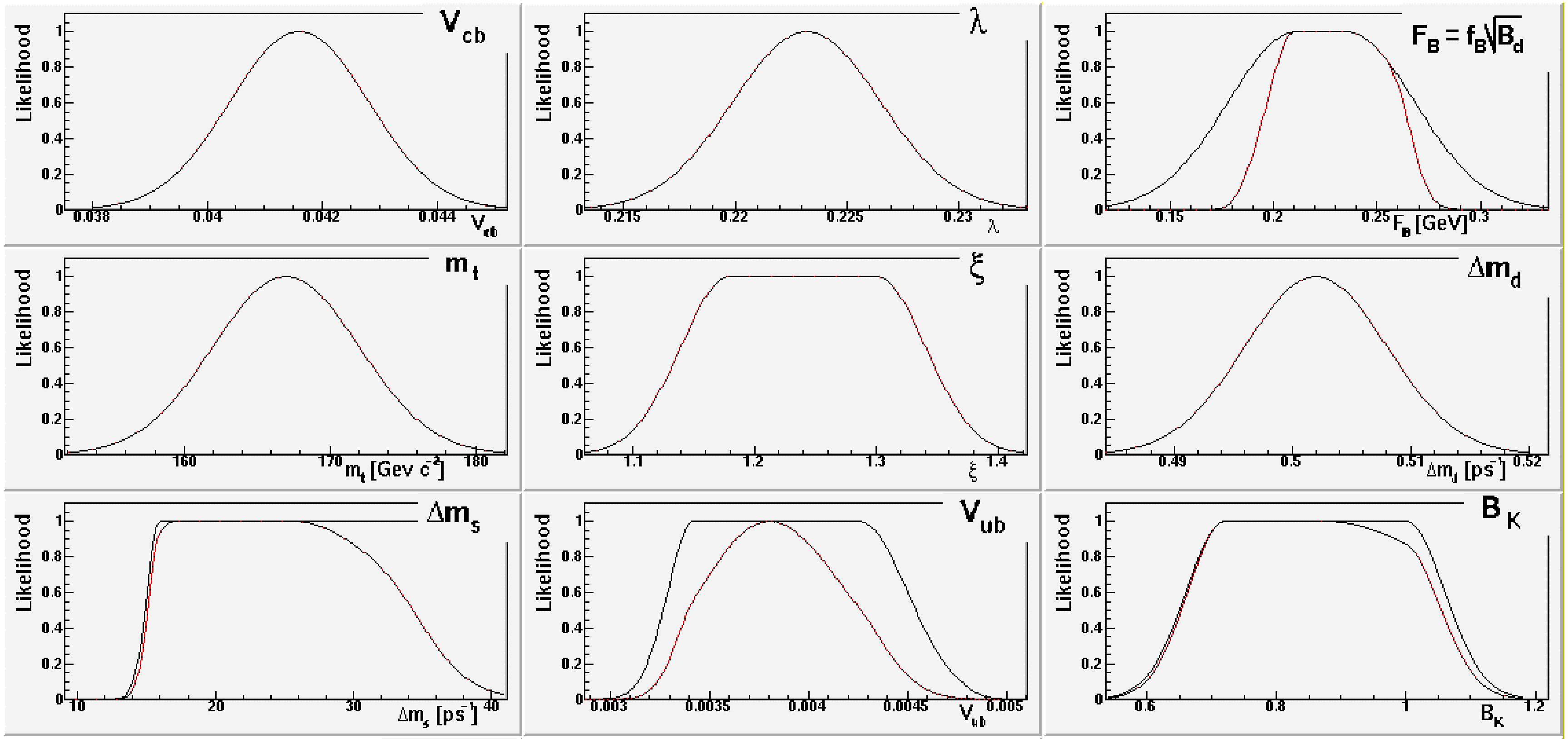
Including CP violation measurements into the unitarity fit:

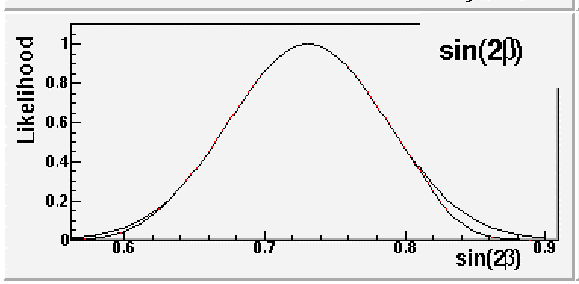


$\bar{\rho} = 0.21 \pm 0.08 \pm 0.05$, $\bar{\eta} = 0.34 \pm 0.04 \pm 0.02$

Parameter values before and after the unitarity fit:

ckm
Lfit





$\Delta m_s = (14 - 39)/\text{ps}$, 95%CL

$|V_{ub}| = (3.82 \pm 0.37)\ 10^{-3}$

V_{ud}	V_{us}	V_{ub}
V_{cd}	V_{cs}	V_{cb}
V_{td}	V_{ts}	V_{tb}

Summary: Rich experimental and theoretical progress in the determination of CKM matrix magnitudes.

Experimental problems: $G_A/G_V(n)$, $\Gamma(K_{l3})$, $F(1)\cdot|V_{cb}|$ ...

Important inputs missing: Δm_s, $\tau(t)$ ...

More statistics will help $|V_{cb}|_{incl}$ and $|V_{ub}|$

„Matrix is unitary“ within ± 1.8 σ, using my present error estimates.

Assuming „unitarity“, i. e. no New Physics, and including $\varepsilon(K^0)$, $\sin 2\beta$:

$$\lambda = 0.2235 \pm 0.0033 \quad (\pm 1.5\ \%)$$

$$A\,\lambda^2 = 0.0415 \pm 0.0011 \quad (\pm 2.7\ \%)$$

$$A\,\lambda^3 \sqrt{\rho^2 + \eta^2} = 0.0038 \pm 0.0004 \quad (\pm 10\ \%)$$

$$\mathrm{atan}\,(\eta/\rho) = (58 \pm 19)^\circ \quad (\pm 5\ \%\ \text{of}\ 360^\circ)$$

Hirarchy of magnitudes 1, λ, λ^2, λ^3 was also a hirarchy of precision.

No longer now, $A\lambda^2$ is already better known than A.