Klaus R. Schubert, TU Dresden

27 October 2008, B-Factory Symposium

in recognition of the achievements of PEP-II and BABAR

Quark Mixing at BABAR

bmb+f - Förderschwerpunkt

BABAR

Großgeräte der physikalischen Grundlagenforschung

Quark Mixing in the St. Model: Origin of observed CP Violation

Manifestations: K^0, D^0, B^0 Oscillations and

CKM Hirarchy of Weak Decays

BABAR Contributions to B^0 and D^0 Oscillations and to

Determinations of V_{us}, V_{cb}, V_{ub}, (V_{ts}), V_{td}

Deviations from the CKM Description of Quark Mixing?

Without Quark Mixing No CP Violation *)

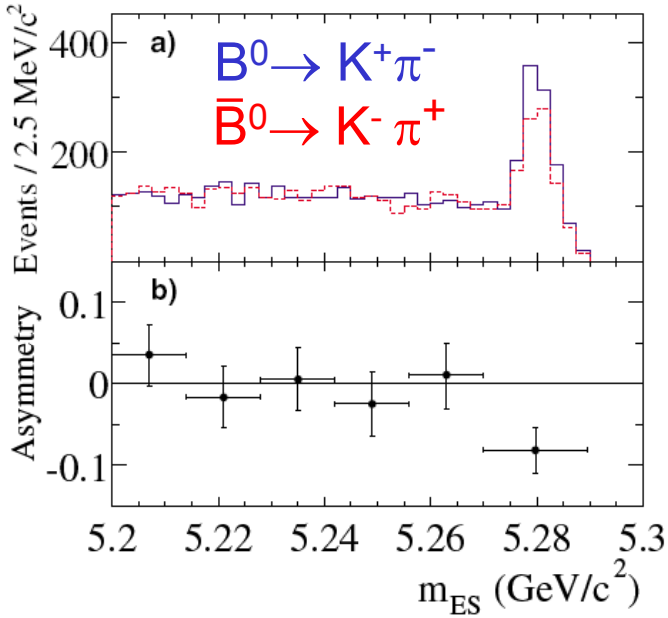
Example: Discovery of „Direct CPV“

in $B \to K^+\pi^-$, $K^-\pi^+$ PRL 93(2004)131801

230 M $B\bar{B}$, 1600 $K\pi$ Decays. $N(K^+) > N(K^-)$

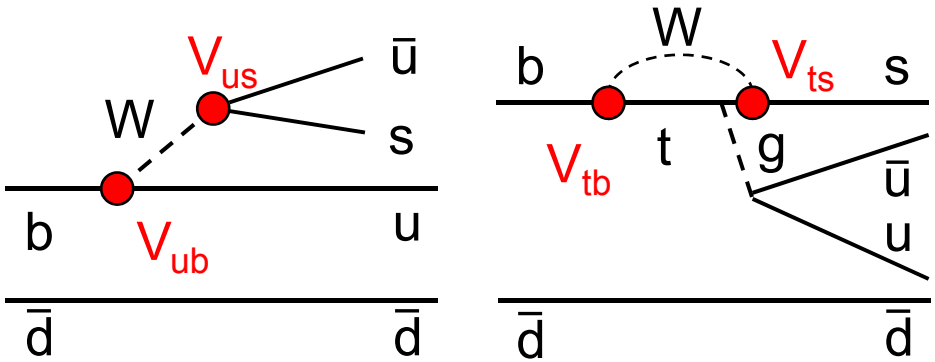
$(N^+-N^-)/(N^++N^-) = 0.13$ with 4.2 σ from 0

First CPV Observation without any Time Info.

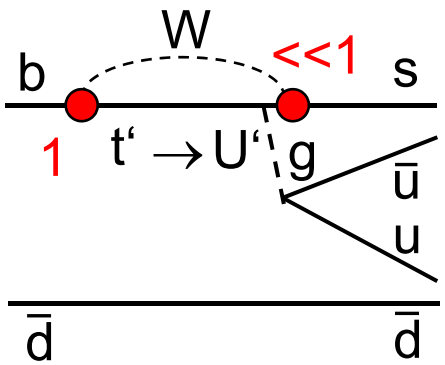


Explanation: CPV is an interference *)

of two decay contributions; here



A slightly different view on the 2nd graph:



$U' = \alpha t' + \beta c' + \gamma u'$

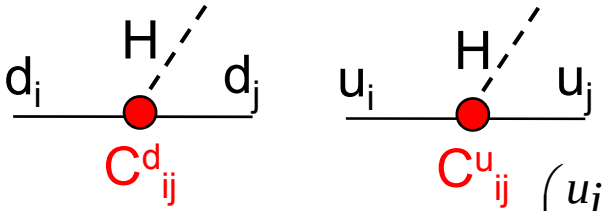
*) in the Standard Model

Quark Mixing in the St. Model

Quarks (d, s, b) (u, c ,t) couple to both W and H fields.

Without H, perfect symmetry between d_1 d_2 d_3 and also between u_1 u_2 u_3.

Most general qHq couplings:



„Rotation“ in d- (u-) space diagonalizes C^d (C^u)

Gauge couplings uWd require doublets $\begin{pmatrix} u_{iL} \\ d_{iL} \end{pmatrix}$. Rotations rotate the doublets and either diagonalize C^d or C^u. The difference between the two is V:

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

The 3x3 unitary matrix V has 4 parameters, e.g. $|V_{us}|$, $|V_{cb}|$, $|V_{ub}|$, $\mathrm{Im}(V_{ub}V^*_{ud}V_{cd}V^*_{cb})$

CPT requires:

$$\begin{pmatrix} \begin{pmatrix} \bar{u}_R \\ \bar{d}'_R \end{pmatrix} \\ \begin{pmatrix} \bar{c}_R \\ \bar{s}'_R \end{pmatrix} \\ \begin{pmatrix} \bar{t}_R \\ \bar{b}'_R \end{pmatrix} \end{pmatrix} = V^* \begin{pmatrix} \begin{pmatrix} \bar{u}'_R \\ \bar{d}_R \end{pmatrix} \\ \begin{pmatrix} \bar{c}'_R \\ \bar{s}_R \end{pmatrix} \\ \begin{pmatrix} \bar{t}'_R \\ \bar{b}_R \end{pmatrix} \end{pmatrix}$$

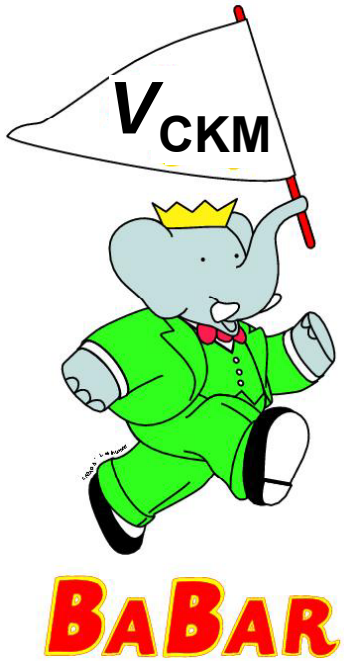
If $V^* \neq V$, q mixing violates CP.

Only at $T \approx m_h$ q get masses.

$V = V_{KM} \rightarrow V_{CKM}$ (1973, 1987)

One of the first manifestations of quark mixing was $K^0\bar{K}^0$ mixing. But ...

BABAR Publications on Quark Mixing



From 19 Mar 2001 to 20 Oct 2008

BABAR has published

349 Journal papers on physics results

- 165 in Phys. Rev. Letters
- 184 in Phys. Rev. D

53 of them on Quark Mixing topics (15%)

- 7 on $D^0\bar{D}^0$ Mixing
- 8 on $B^0\bar{B}^0$ Mixing
- 13 on V_{cb} topics
- 18 on V_{ub} topics
- 4 on V_{ts} topics
- 3 on V_{td} topics

Main obligations: Check „if V_{CKM} is unitary“ and determine its 4 parameters

$D^0\bar{D}^0$ Mixing

All meson systems which are allowed to mix are now observed to mix:

$K^0\bar{K}^0$	$K_S^0\ K_L^0$	1956,	$\chi = 0.498$, $\Delta\Gamma$, Δm
$B^0\bar{B}^0$	$B_h^0\ B_\ell^0$	1987,	$\chi = 0.19$, Δm
$B_s\bar{B}_s$	$B_{sh}\ B_{s\ell}$	2006,	$\chi = 0.499$, Δm, $\Delta\Gamma$ ($\neq 0$ with 1.5σ),
$D^0\bar{D}^0$	$D_+^0\ D_-^0$	2007,	$\chi \approx 0.7\cdot 10^{-4}$ ($\neq 0$ with $9\ \sigma$), Δm, $\Delta\Gamma$ ($\neq 0$ with 2σ)

Common Mixing Phenomenology:

$$M_h(t) = \left(p\,M + q\,\overline{M}\right)\cdot e^{-i(m+\Delta m/2)t-(\Gamma/2+\Delta\Gamma/4)t}$$

$$M_l(t) = \left(p\,M - q\,\overline{M}\right)\cdot e^{-i(m-\Delta m/2)t-(\Gamma/2-\Delta\Gamma/4)t}$$

$x = \Delta m/\Gamma$, $y = \Delta\Gamma/2\Gamma$

$\chi = (x^2+y^2)/(2+2x^2)$

$|q/p| \approx 1$ in all four systems $\Downarrow$

All four M_h and M_ℓ are $\approx$ CP eigenstates

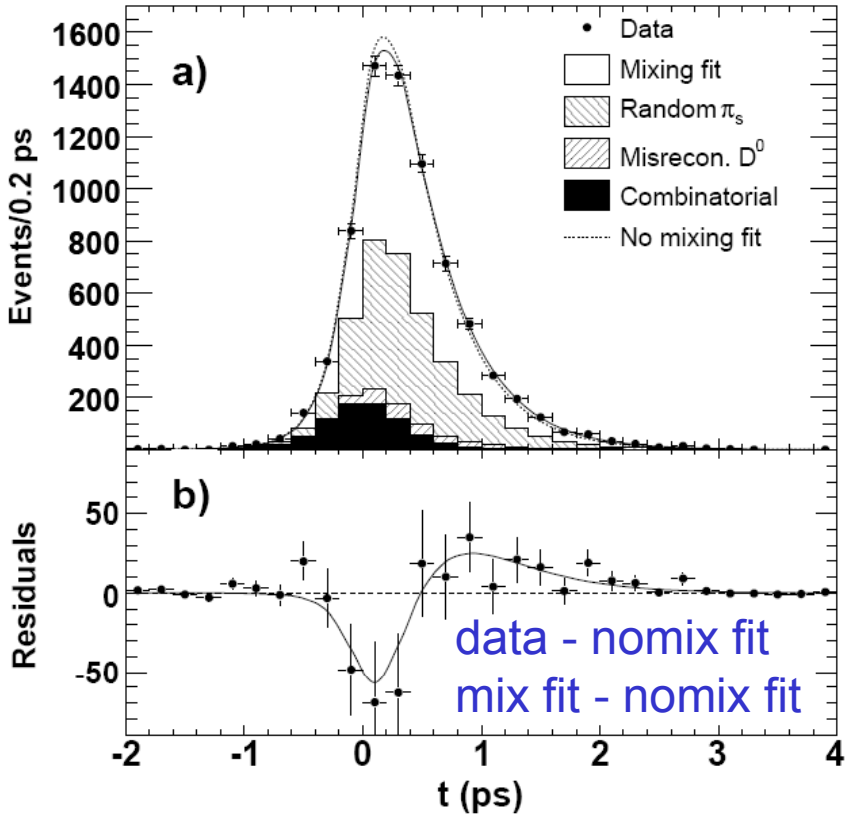
Three independent pairs of properties:

heavy & ℓight
Long- & Shortliving
CP = +1 & CP = -1

K^0	L = - = h
B_s	L = - (1.5σ) = ?
D^0	L = - (4σ) = ℓ (2σ)
B^0	L = ? = ?

$D^0\bar{D}^0$ Mixing: y‘ and $x^2 + y^2$ in $D^0 \to \bar{D}^0 \to K^+\pi^-$

$$N_{K^+\pi^-}(t) = N_{K^-\pi^+}(0)\, e^{-\Gamma t}\left[R_D + \sqrt{R_D}\, y'\,\Gamma t + \frac{x'^2 + y'^2}{4}(\Gamma t)^2\right] \qquad \begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix}$$

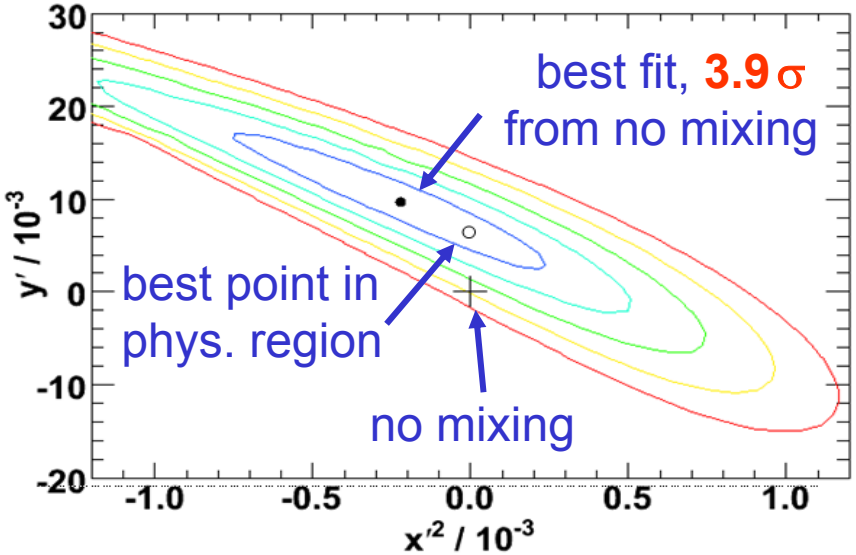


PRL 98(2007)211802 384 / fb

R_D: $(3.03 \pm 0.16 \pm 0.10) \times 10^{-3}$

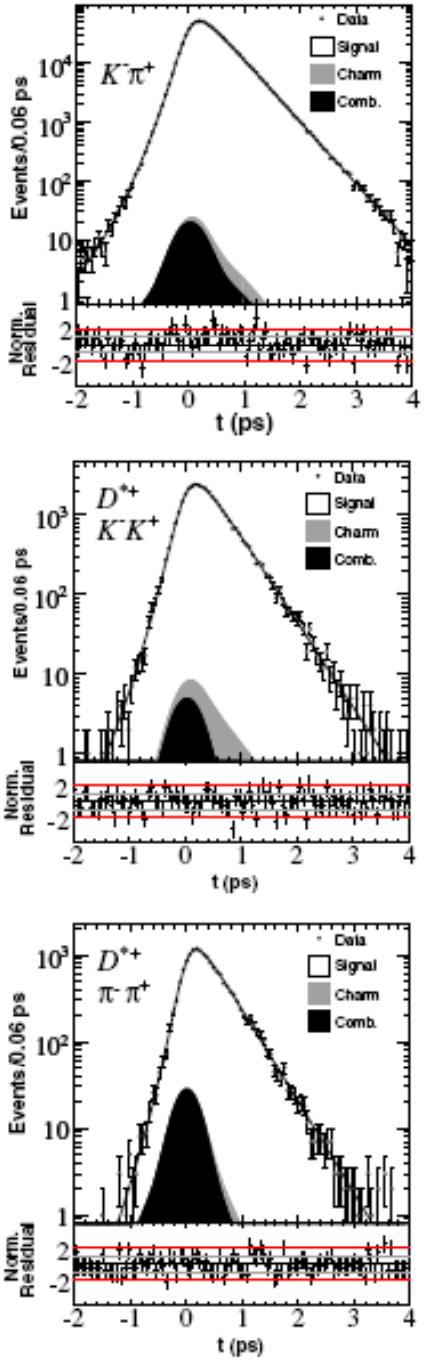
x'^2: $(-0.22 \pm 0.30 \pm 0.21) \times 10^{-3}$

y': $(9.7 \pm 4.4 \pm 3.1) \times 10^{-3}$



CDF PRL 100(2008)121802 1.5/fb $x'^2 = (-0.12 \pm 0.35)10^{-3}$, $y' = (8.5 \pm 7.6)10^{-3}$, **3.8 σ**

$D^0\bar{D}^0$ Mixing: **y in τ(KK,$\pi\pi$,Kπ)**



PRD 78(2008)011105(R)

384 / fb

$e^+e^- \rightarrow D^{*+}X$, $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-K^+, \pi^-\pi^+, K^-\pi^+$

$$\frac{1}{\tau(\mathrm{KK})} = \frac{1}{\tau(\pi\pi)} = \frac{1+y}{\tau(\mathrm{K}\pi)}$$

$y = (1.24 \pm 0.39 \pm 0.13)\ 10^{-2}$

3 σ

PRL 98(2007)211808

540 / fb

$$y = (1.31 \pm 0.32 \pm 0.25) \cdot 10^{-2}$$

3.2 σ

<u>HFAG Aug/08 average</u> (together with others):

$(1.07 \pm 0.26)\ 10^{-2}$ **4.2 σ**

$x^2 + y^2$ in $D^0 \to \bar{D}^0 \to K^+\ell^-\bar{\nu}$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$

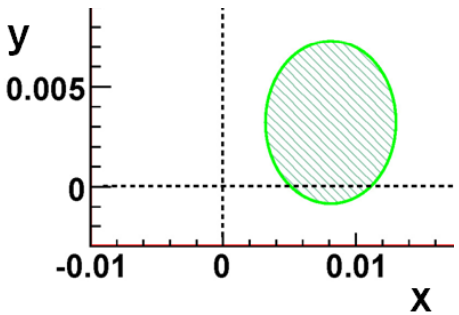
$K^+\ell^-\bar{\nu}$	$\chi = (x^2 + y^2)/2 = (0.4^{+7}_{-6})10^{-4}$	344 / fb	PRD 76(2007)014018
$K^+\ell^-\bar{\nu}$	$(1.3 \pm 2.2 \pm 2.0)10^{-4}$	492 / fb	PRD 77(2008)112003
$K^+\pi^-\pi^0$	3.2×10^{-4} with 3.2σ	384 / fb	arXiv:0807.4544 → PRL
$K^+\pi^-\pi^+\pi^-$	$(1.9 \pm 1.6)10^{-4}$	230 / fb	hep-ex/0607090(2006)

x and y from $D^0 \to K^0_S\pi^+\pi^-$ Dalitz Plot Analysis

$$x = (0.80 \pm 0.29 \pm^{0.13}_{0.16})10^{-2}$$

$$y = (0.33 \pm 0.24 \pm^{0.10}_{0.14})10^{-2}$$

2σ from no mixing



540 / fb

PRL 99(2007)131803

$D^0\,\bar{D}^0$ Mixing: Summary

$D^0(t) \rightarrow K^+\pi^-$

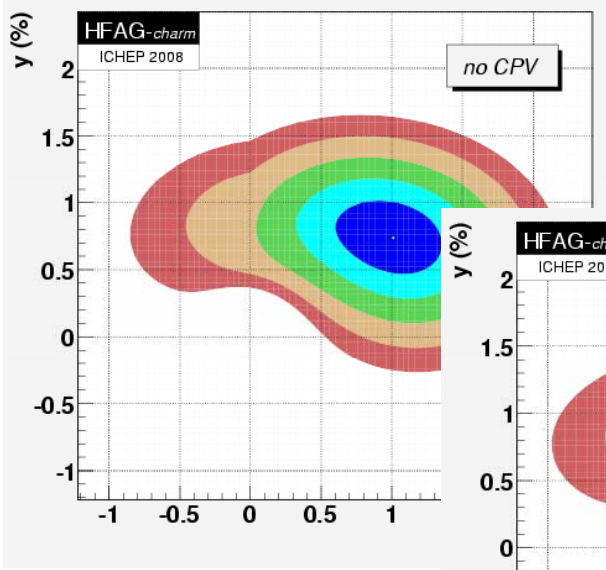
$\Rightarrow (y', x'^2) \neq (0,0)$ with 4 σ

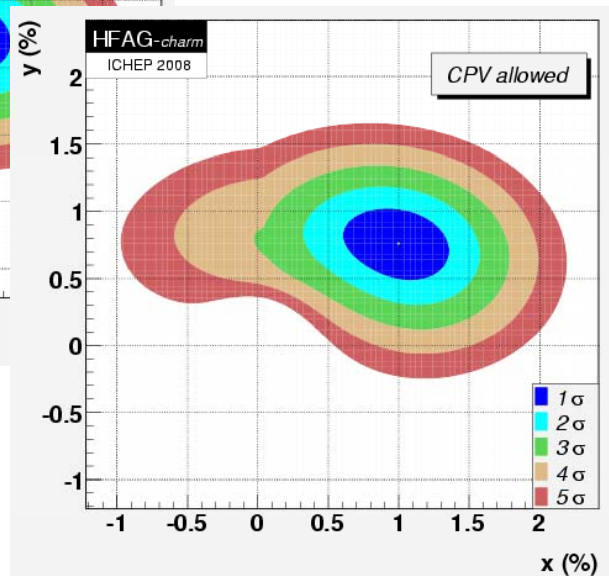
$\tau(K^+K^-, \pi^+\pi^-)/\tau(K^-\pi^+)$

$\Rightarrow y \neq 0$ with 3.2 and 3 σ

$D^0(t) \rightarrow K^0_S\,\pi^+\pi^-$ Dalitz Plot

$\Rightarrow (x,y) \neq (0,0)$ with 2 σ





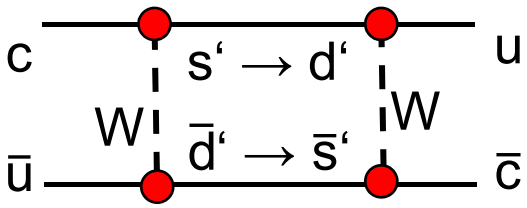
<u>HFAG average August 2008:</u>

$x = (10.1 \pm 2.4)\,10^{-3}$, $y = (7.3 \pm 1.8)\,10^{-3}$

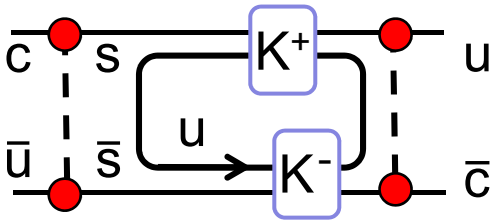
$\Rightarrow \chi = (x^2+y^2)/2 = (0.77 \pm 0.25)\,10^{-4}$

of all produced D^0 decay as $\bar{D}^0$, $\chi \neq 0$ with 9.8 σ. No CPV(D^0) observed.

<u>St. Model Expectation:</u>



negligible



$\chi \leq 10^{-4}$

$B^0 \bar{B}^0$ Mixing

PDG 2008 uses 3 BABAR results on Δm:

2002 21/fb $\ell^\pm$ - $\ell^\pm$, $A = (N^{+-}-N^{\pm\pm})/(N^{+-}+N^{\pm\pm})$

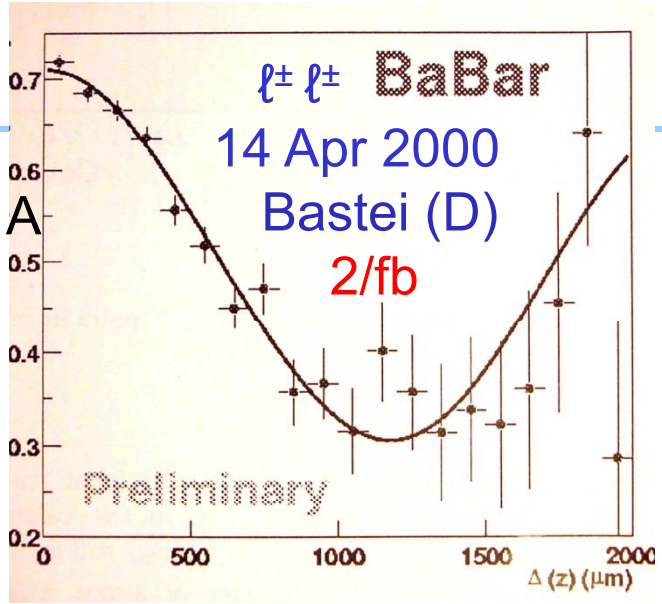
2002 30/fb B^0(full.rec) - CPtag,

2006 81/fb $B^0 \to D^* \ell \nu$(part.rec) - $\ell^\pm$

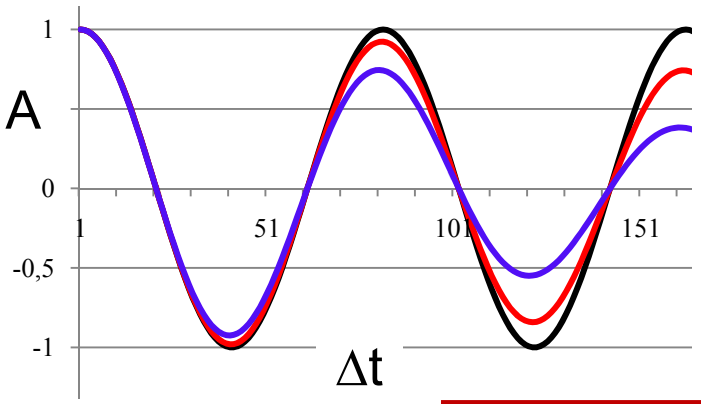
PRD 73(2006)012004

Present PDG Mean $\Delta m=(0.507\pm0.005)/ps$

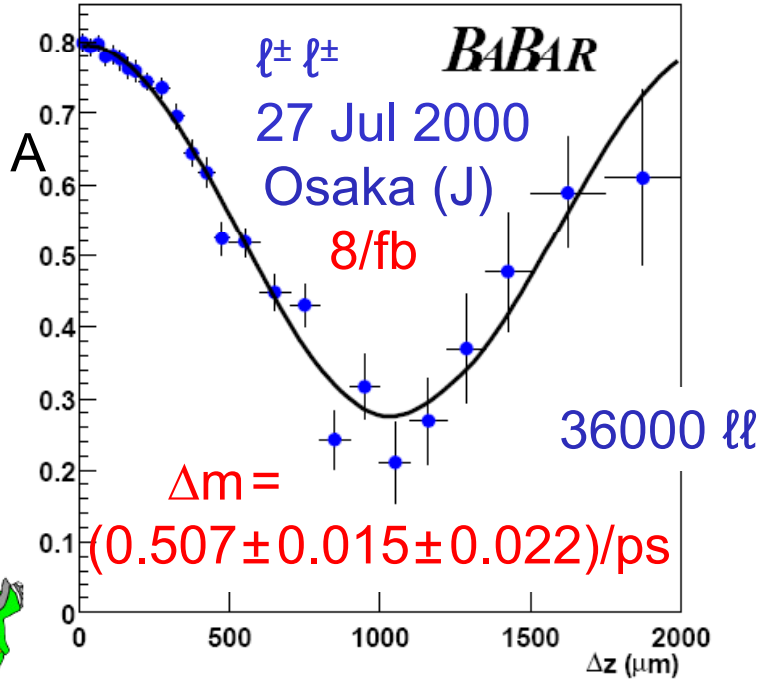
dominated by BABAR 06 + BELLE 05



B^0(full.rec) - CPtag:



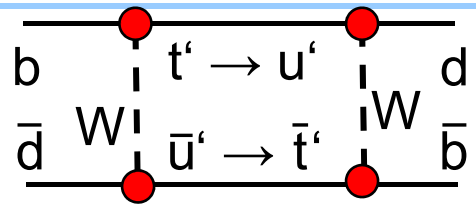
$\Delta\Gamma/2\Gamma=0$
$=0,05$
$=0,1$



81/fb $|\Delta\Gamma/2\Gamma|<0.04$ PRD 70(2004)012007

$B^0\bar{B}^0$ Mixing; CP, T and CPT

St. Model Expectation:



$$\Delta m = \frac{G_F^2 m_B f_B^2 B_B \eta_B}{6\pi^2} |V_{td}|^2 |V_{tb}|^2 f\left(m_t^2, m_W^2\right)$$

$$\text{LQCD 2007}: f_B^2 B_B = (223 \pm 8 \pm 16)^2 \text{MeV}^2$$

$$\Delta\Gamma / 2\Gamma \approx 2 \cdot 10^{-3}, \quad \left|\frac{q}{p}\right| - 1 = o\left(10^{-3}\right)$$

$|V_{tb}V_{td}| = (8.1 \pm 0.6)\ 10^{-3}$

Search for CP and T Violation in Mixing: PRL 96(2006)251802

$$\frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$ in dilepton events measures the CP- and T-violating asymmetry $\bar{B}^0 \to B^0$ / $B^0 \to \bar{B}^0$

211/fb

$|q/p| - 1 = (-0.8 \pm 2.7 \pm 1.9)\ 10^{-3}$, PDG 08: $(1.8 \pm 1.8)\ 10^{-3}$ with D0 & Belle 2006

CPT Test in $B^0\bar{B}^0$ Mixing: same paper

$$\frac{N^{+-}(\Delta t > 0) - N^{+-}(\Delta t < 0)}{N^{+-}(\Delta t > 0) + N^{+-}(\Delta t < 0)}$$

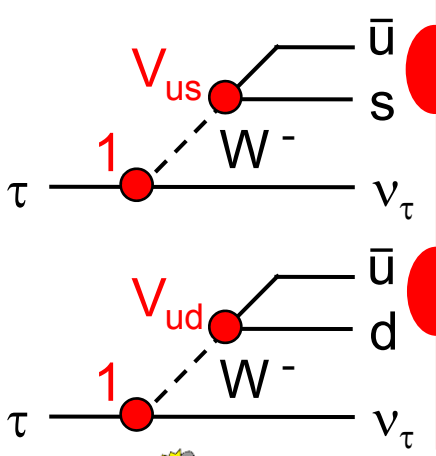
measures the CPT-violating asymmetry $B^0 \to B^0$ / $\bar{B}^0 \to \bar{B}^0$. Results:

$$\delta = -\frac{z}{2} = -\frac{\delta m}{\Delta m} + i\frac{\delta\Gamma}{2\Delta m} = \frac{(3.5 \pm 1.9 \pm 1.0) \cdot 10^{-3}}{\text{ps} \cdot \Delta\Gamma} + i(7.0 \pm 3.6 \pm 1.6) \cdot 10^{-3}$$

{δ from Charpak & Gourdin 1967}

V_{us}

Contributions from our 580 M τ-lepton pairs; exclusively and inclusively



K-

$$\frac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^- \to \pi^- \nu_\tau)} = \frac{f_K^2}{f_\pi^2}\frac{|V_{us}|^2}{|V_{ud}|^2}\frac{(1-m_K^2/m_\tau^2)^2}{(1-m_\pi^2/m_\tau^2)^2}$$

π-

$f_K/f_\pi = 1.189 \pm 0.007$

LQCD 2008, Follana + al

1 or 3 K + X

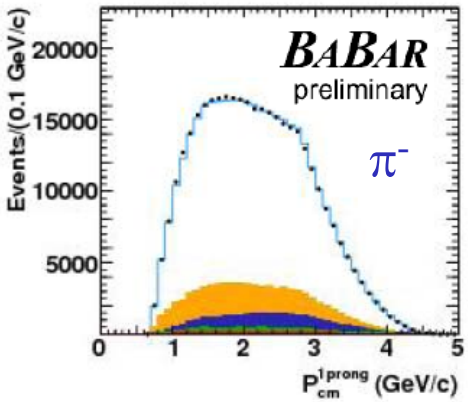
$$\frac{\Gamma_{s\bar{u}}}{\Gamma_{d\bar{u}}} + \delta(m_s) = \frac{|V_{us}|^2}{|V_{ud}|^2}$$

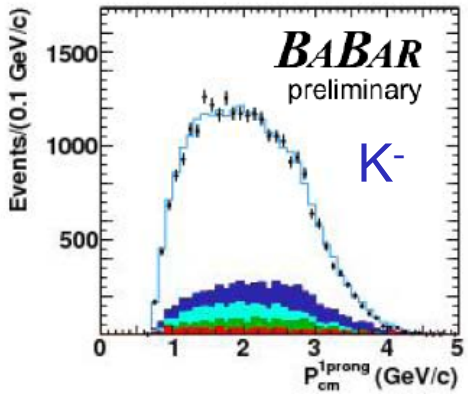
0 or 2 K + X

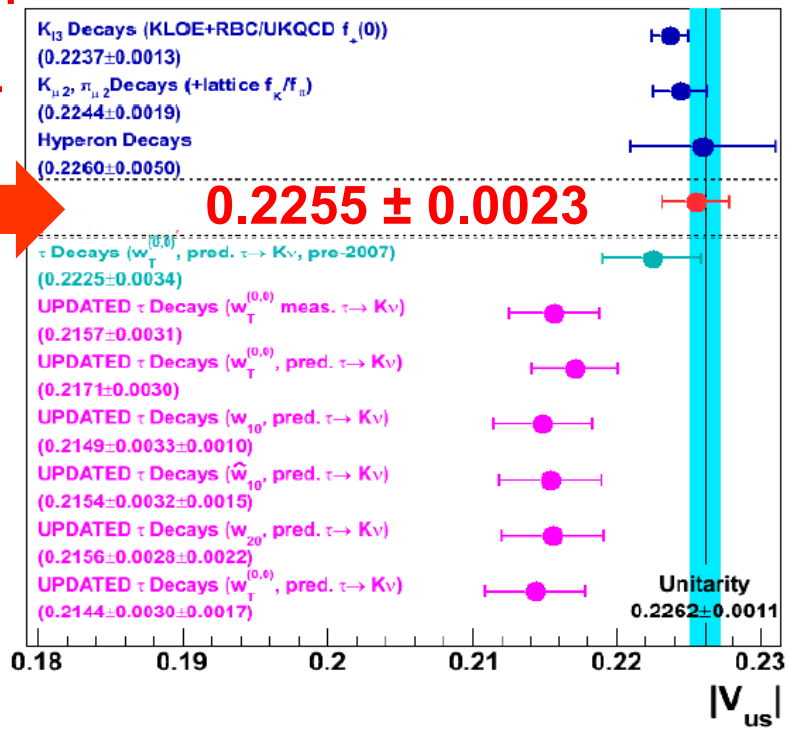
δ from Gamiz + al 2005 + ...

I. Nugent @ TAU 08

467/fb

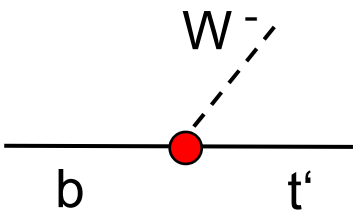






$$\Gamma(\tau \to K\nu)/\Gamma(\tau \to \pi\nu) = (6.53 \pm 0.06 \pm 0.09)10^{-2}$$

V_{cb}

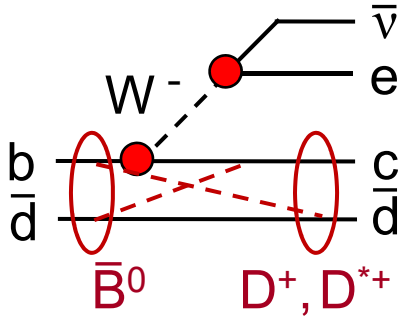


$t' = V_{tb}\,t + V_{cb}\,c + V_{ub}\,u$, coherent at time of W emission, decoherent at time of meson formation:

$\Gamma(B \to c+X) \sim |V_{cb}|^2$, $\Gamma(B \to t+X) = 0$, $\Gamma(B \to u+X) \sim |V_{ub}|^2$

Rate measurements allow determination of $|V_{cb}|$,

Smallest influence of the strong interaction:



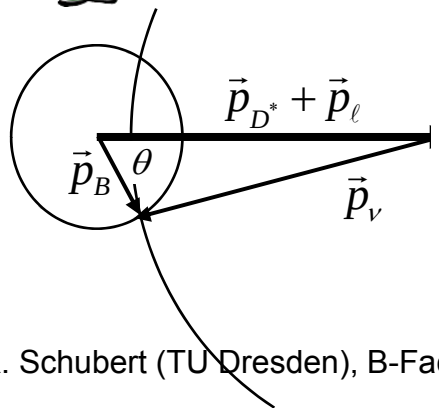
Best-studied reconstructed mode: $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$

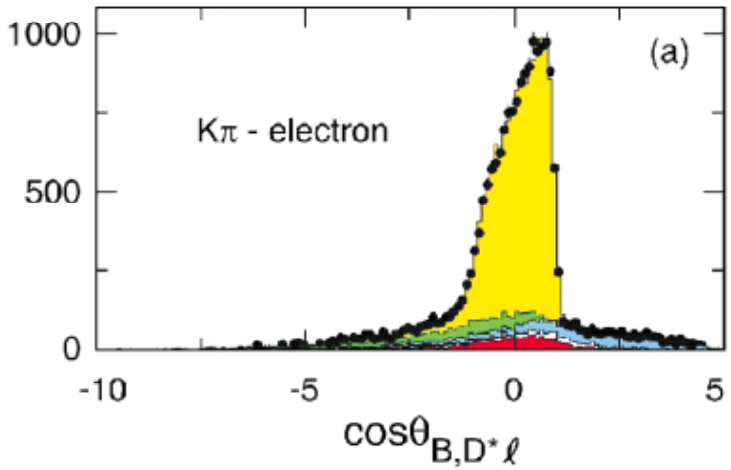
BF ~ 5%, str.int.contr. ~ 10% if $d\Gamma/dq^2$ at q^2_{max}:

Latest result:

PRD 77(2008)032002  79/fb

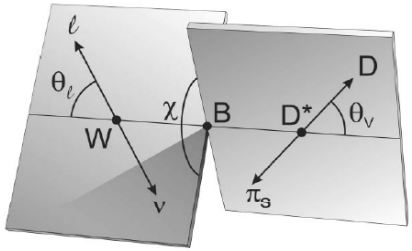
„Full" reconstruction of the decay with $D^{*+} \to (K^-\pi^+)_D\,\pi^+_{slow}$ and $\cos\Theta_{B,D^*\ell}$



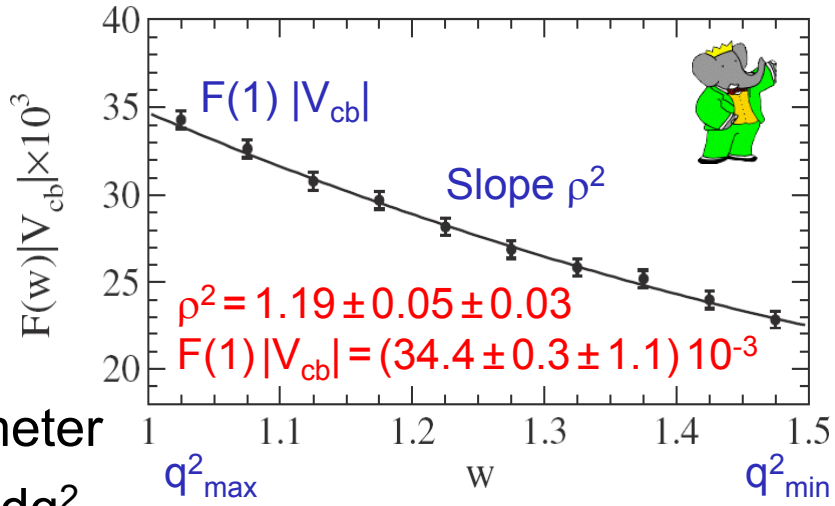


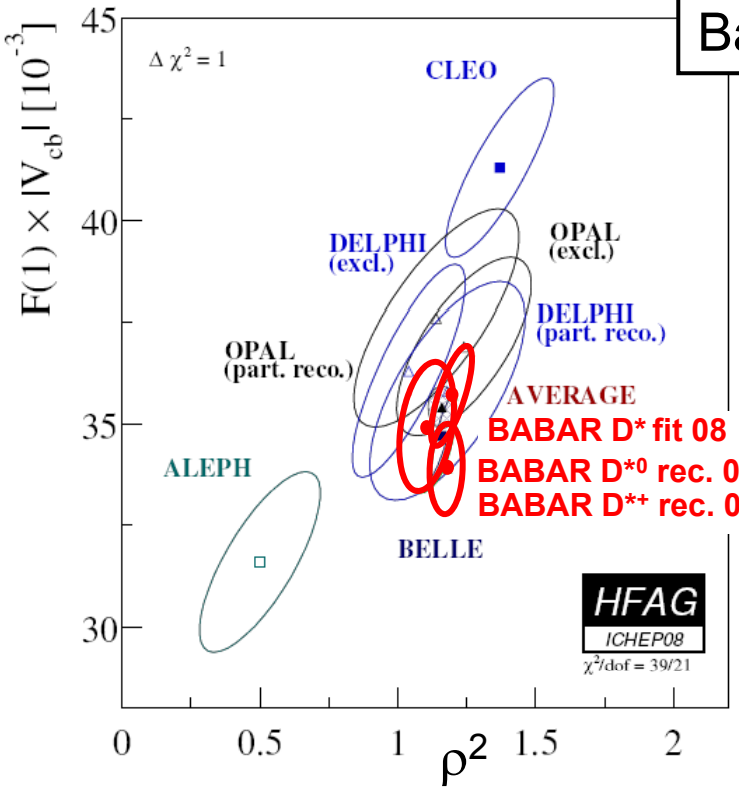
V_{cb} continued

Full information on $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$ is in the rate $d^4\Gamma/dq^2\, d\chi\, d\cos\Theta_\ell\, d\cos\Theta_V$.



Integration over the angles with fitted parameter values R_1, R_2 gives $d\Gamma/dq^2$





Bad agreement ⇒ Look for new approaches:

PRL 100(2008)231803 $B^- \to D^{*0}\ell^-\bar{\nu}$ 205/fb

$D^{*0} \to (K^-\pi^+)_D\, \pi^0_{slow}$

$\rho^2 = 1.16 \pm 0.06 \pm 0.08$

$F(1)|V_{cb}| = (35.9 \pm 0.6 \pm 1.4)\, 10^{-3}$

arXiv:0809.0828 $B \to (D^0, D^\pm)\, \ell^-\bar{\nu}$ 207/fb

$p_D, p_\ell, \Theta_{B,D\ell}$ fit

$\rho^2 = 1.21 \pm 0.02 \pm 0.07$

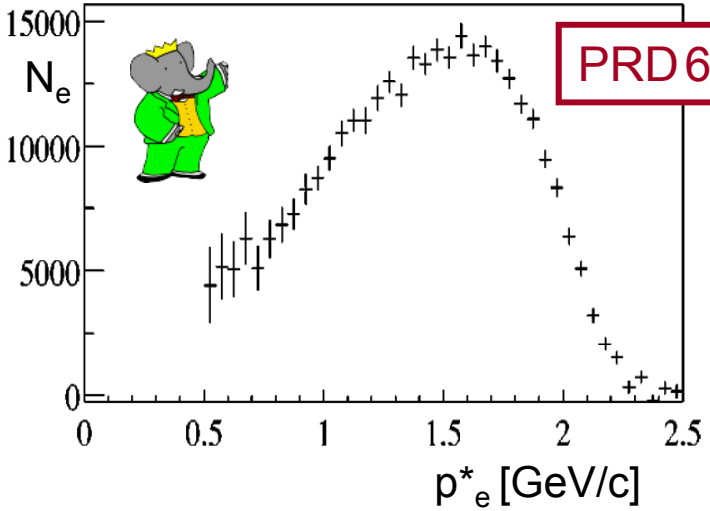
$F(1)|V_{cb}| = (35.7 \pm 0.2 \pm 1.2)\, 10^{-3}$

HFAG+LQCD: $|V_{cb}|_{D^*} = (38.5 \pm 0.7 \pm 1.0)\, 10^{-3}$

HFAG+LQCD: $|V_{cb}|_D = (39.2 \pm 1.6 \pm 0.9)\, 10^{-3}$

My average: $|V_{cb}|_{excl} = (38.6 \pm 0.6 \pm 1.0) 10^{-3}$

V_{cb} (inclusive)



PRD 69(2004)111104 47/fb Momentum spectrum of electrons in $B\bar{B} \to e^+\nu X\, e^-\bar{\nu} X$ events

$\Rightarrow$ *BF*($B \to e^+\nu X$, E_e>0.6 GeV/c)

=(10.36 ± 0.06 ± 0.23)%, 0.98 X_c + 0.02 X_u

$$\Gamma\left(B \to e^+ \nu\, X_c, E_e > E_{\min}\right) = |V_{cb}|^2 \cdot f_{\mathrm{HQE}}\left(E_{\min}; m_b, m_c, \mu_\pi^2, \mu_G^2, \rho_D^3, \rho_{LS}^3\right)$$

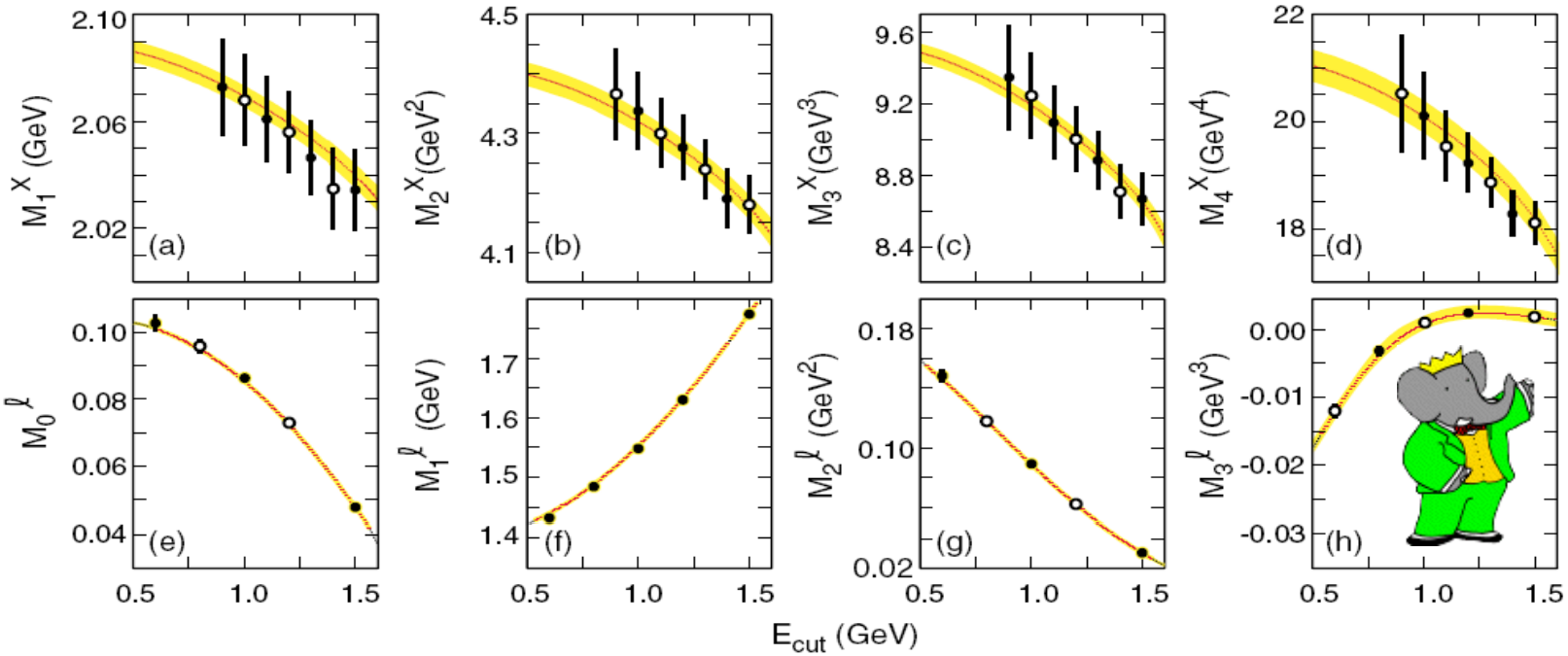
HQE = effective QCD with expansion in Λ_{QCD}/m_b

The shape of the spectrum, with more precision its moments $\langle E_e^k \rangle$, k=1,2,3 for 5 different E_{min}, determine the parameters m_b ... ρ_{LS}^3 and therewith $|V_{cb}|$ and the extrapolated *BF* for E_{min}=0. The HQE fit in the „kinetic scheme“ in PRL 93(2004)011803 includes moments $\langle m_X^k \rangle$, k=1...4 of the mass spectrum of the X_c system for 8 different E_{min}. The 2004 BABAR+HQE fit finds

$$|V_{cb}|_{incl} = (41.4 \pm 0.4 \pm 0.7)\ 10^{-3}.$$

The credibility is demonstrated by the quality of the overconstraining fit:

more V_{cb} inclusive



$|V_{cb}|_{incl}$ (BABAR 2004) $= (41.4 \pm 0.4 \pm 0.7)\,10^{-3}$

$|V_{cb}|_{incl}$ (HFAG 2008) $= (41.7 \pm 0.4 \pm 0.6)\,10^{-3}$ incl. CLEO, BELLE, DELPHI and moments from $B \to X_s \gamma$

$|V_{cb}|_{excl}$ (HFAG+LQCD) $= (38.6 \pm 0.6 \pm 1.0)\,10^{-3}$

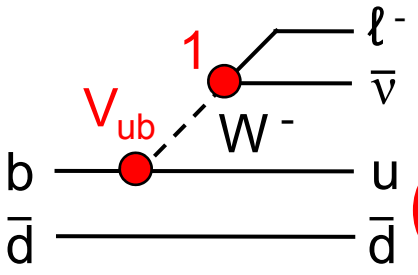
Inclusive ±1.7%, exclusive ± 3.0%. Tension between the two is 2.3 σ.

V_{ub}

Since 1990 (ARGUS, CLEO) $|V_{ub}/V_{cb}| \approx 0.1$, i.e. $N(B \to u+X)/N(B \to c+X) \approx 0.02$,

Rate measurements for determinations of $|V_{ub}|$ have bg/signal ≈ 50.

Cleanest ways: exclusive and inclusive semileptonic decays



3 papers on $\pi \ell \nu$:

$$\frac{d\Gamma}{dq^2} = |V_{ub}|^2 \frac{G_F^2 p_\pi^3}{24\pi^3} \left| f_+(q^2) \right|^2$$

π^-

$f_+(q^2)$ from LQCD for large q^2

from LCSR for small q^2

X_u

Integrate $\dfrac{d^3\Gamma(B \to X_u \ell \nu)}{dp_\ell \, dq^2 \, dm_X^2}$

over optimized regions of the lepton momentum, $q^2(\ell\bar{\nu})$, and the mass of X_u

PRL 98(2007)091801  206/fb

$\pi^+ \ell \nu$ untagged, i.e. $B\bar{B} \to X + \pi^+ \ell \nu$

$BF = 1.46 \cdot 10^{-4} \pm 11\%$, $|V_{ub}| = 3.8 \cdot 10^{-3} \pm 15\%$

PRL 97(2006)211801  211/fb

tagged, $B\bar{B} \to (D^{(*)} \ell \nu$ or had.rec$) + (\pi^+, \pi^0) \ell \nu$

$BF = 1.33 \cdot 10^{-4} \pm 15\%$, $|V_{ub}| = 3.6 \cdot 10^{-3} \pm 15\%$

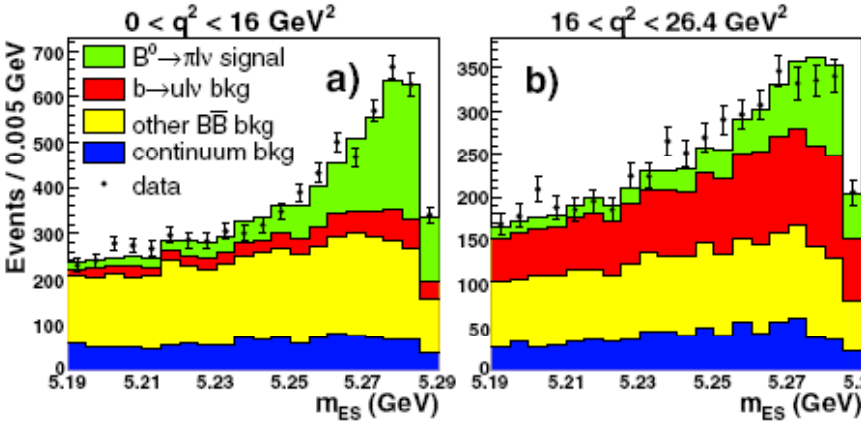
newest paper: PRL 101(2008)081801  348/fb

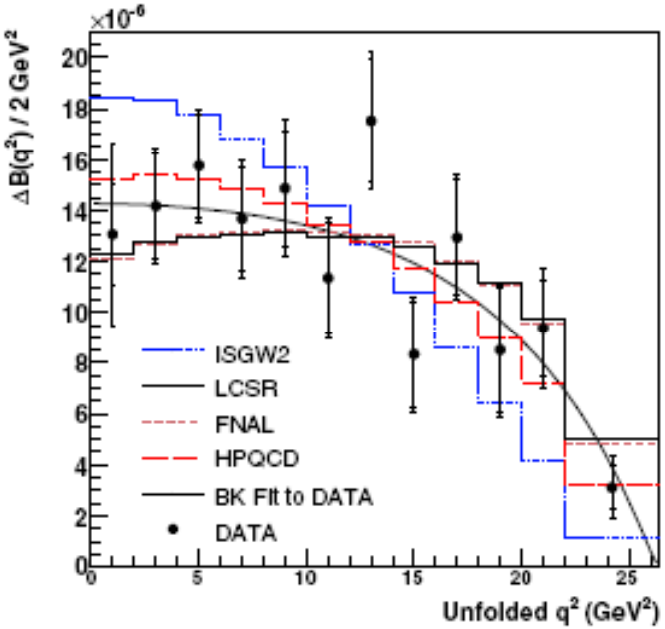
$(\pi^+, \pi^0) \ell \nu$ tagged with $D^{(*)} \ell \nu$

$BF \pm 12\%$, $|V_{ub}| = 3.6 \cdot 10^{-3} \pm 15\%$

V_{ub} (2)

from the untagged $\pi^+\ell\,\nu$ analysis:



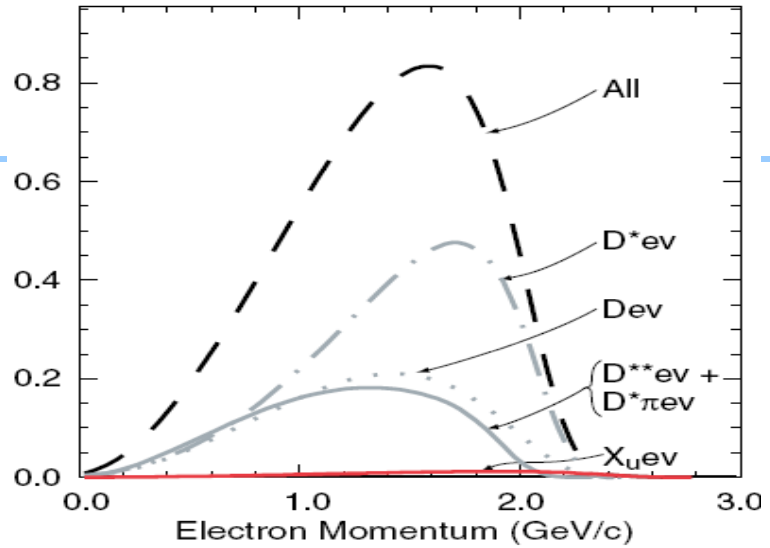


Inclusive $|V_{ub}|$ Measurements

I choose 3 BABAR analyses. $|V_{ub}|$ extraction is done with very refined HQE methods. Expansion converges poorely in the limited p_ℓ q^2 m_X bg-minimizing regions. Non-perturbative „shape functions“ needed; leading parameters now taken from HQE($B\to X_c\ell\bar{\nu}$) results.

- Cut on p_ℓ only
- Cut on p_ℓ and q^2
- Cuts on m_X; m_X and q^2; $P^+ = E_X - p_X$

V_{ub} inclusive



First: p_ℓ only, $p_e > 2.0$ GeV/c, f_u=0.25

PRD 73(2006)012006 (80+10)/fb

$D\ell\bar{\nu}$ and $D^*\ell\bar{\nu}$ modeled, continuum from data, $p_{miss} > 0.5$ GeV/c $\Rightarrow \Delta BF(p_e > 2.0)$,

$|V_{ub}|$(BLNP, HFAG-08) = $4.3 \cdot 10^{-3} \pm 9\%$, stable with p_e cut variations.

2nd: p_ℓ and q^2 PRL 95(2005)111801 (81+10)/fb $p_e > 2.1$ GeV/c and $s_h^{max}(p_e,q^2) < m_D^2$ with $p_\nu = 0.8\, p_{miss} - 0.08$ if $0 < E_{miss} - p_{miss} < 0.8$ GeV/c $\Rightarrow$

$|V_{ub}|$(BLNP, HFAG) = $4.4 \cdot 10^{-3} \pm 11\%$

3rd: m_X, q^2 and $E_X - p_X$ 347/fb

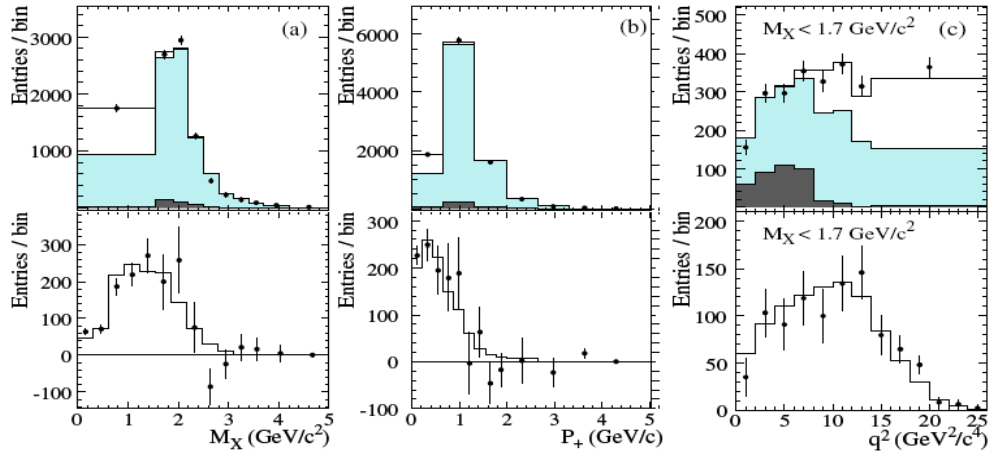
PRL 100(2008)171802

$B\bar{B} \rightarrow B_{reco}\ (\eta = 0.4\%) + X_u\ell\bar{\nu}$

p_ℓ >1 GeV/c, $D^*\ell\bar{\nu}$ veto, K veto

3 regions: m_X<1.55; E_X-p_X<0.66;

M_x<1.7 GeV and q^2>8 GeV^2. $10^3 V_{ub}$(BLNP) = $4.1 \pm 9\%$, $4.4 \pm 10\%$, $3.8 \pm 10\%$



V_{ub} and V_{cb} Summary

HFAG averages all incl. V_{ub} results separately for BNLP, DGE, GGOU, ADFR.

Errors ± 7%, spread ± 5% $\Rightarrow |V_{ub}|_{incl} = 4.1 \cdot 10^{-3} \pm 9\%$

From $B \to \pi \ell \nu$ $|V_{ub}|_{excl} = 3.6 \cdot 10^{-3} \pm 15\%$ $\Delta < 1\sigma$

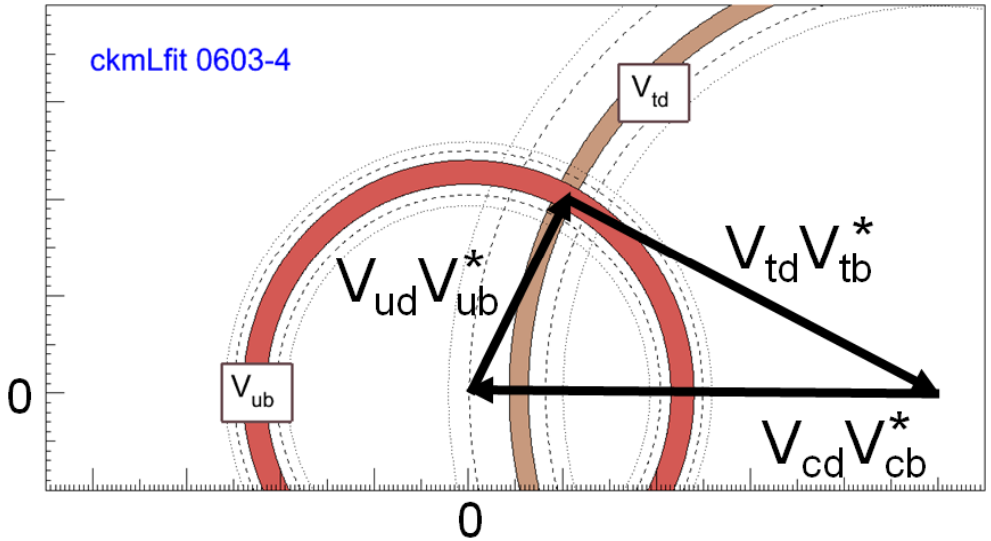
BABAR & BELLE 2000 → 2008: $\sigma(|V_{ub}|) \pm 30\% \to \pm 9\%$

Recalling $|V_{cb}|$: $|V_{cb}|_{excl} = 38.6 \cdot 10^{-3} \pm 3.0\%$

$|V_{cb}|_{incl} = 41.7 \cdot 10^{-3} \pm 1.7\%$ $\Delta = 2.3\sigma$

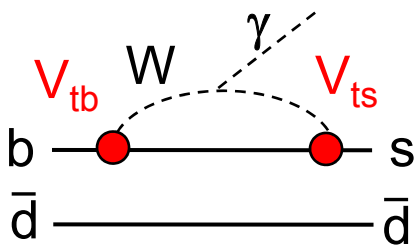
$\sigma(|V_{cb}|) \pm 5\% \to \pm 2\%$

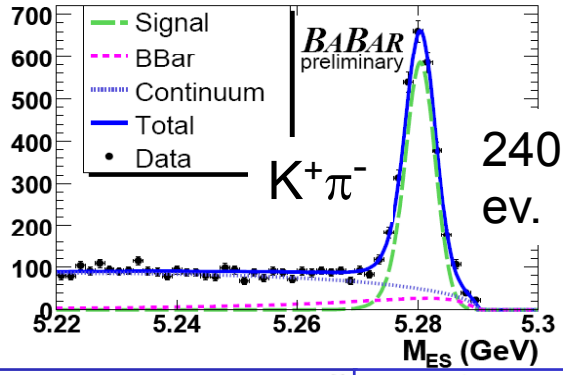
With $|V_{ub}|$, $|V_{cd}|$,
$|V_{us}|$ (mainly $K\ell 3$, but τ is coming),
and $|V_{td}|$ (Δm of B^0, B_s),
the unitarity of the CKM matrix
shows that CP is violated:
Conclusion from only
CP-symmetric observations.
[two solutions; CPV (ε_K, β, γ)
shows $\mathrm{Im}(V_{ud}V_{ub}^*V_{cb}V_{cd}^*) > 0$.]

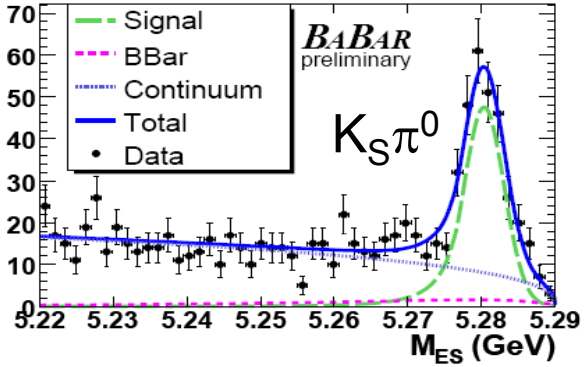


V_{ts} in Decays

$B^{0,+} \to K^{*0,+}\gamma$ arXiv:0808.1915 347/fb Modes $K^+\pi^-$, $K_S\pi^0$, $K^+\pi^0$, $K_S\pi^+$







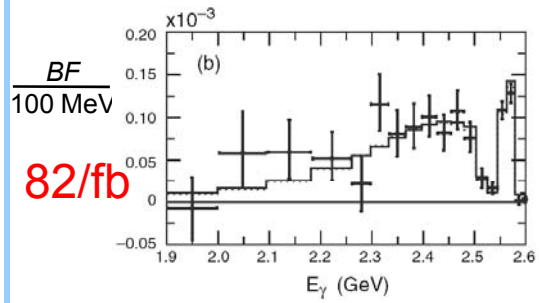
$\mathcal{B}(B^0 \to K^{*0}\gamma) = (4.58 \pm 0.10 \pm 0.16) \times 10^{-5}$ | $\mathcal{B}(B^+ \to K^{*+}\gamma) = (4.73 \pm 0.15 \pm 0.17) \times 10^{-5}$

Precision of formfactor calculation not sufficient for $|V_{tb}||V_{ts}|$, this may change!

$b \to s\gamma$ $|V_{ts}|$ not goal of the 3 analyses; here only for completeness:

PRD 72(2005)052004

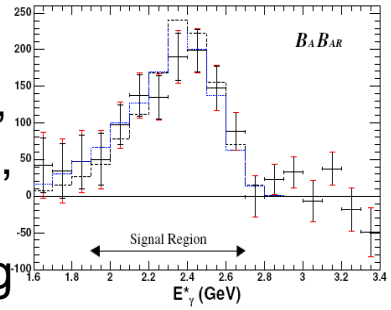
Σ of 4 K* + 34 other modes



PRL 97(2006)171803

82/fb

$B\bar{B} \to \gamma X$, π^0-η-veto, lepton tagging

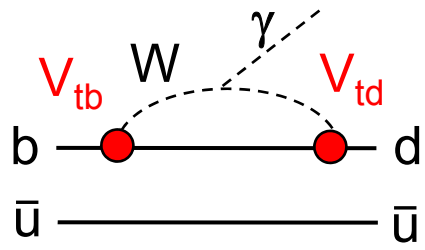


PRL 77(2008)051103

210/fb B_{reco} tags ⇒ smaller but cleaner event sample. BF compatible, but σ(BF) 3 times larger. WA(PDG 08):

$BF(b \to s\gamma) = (35.6 \pm 2.5)10^{-5}$

V_{td} in Decays



$B^+ \to \rho^+ \gamma$

$B^0 \to \rho^0 \gamma$

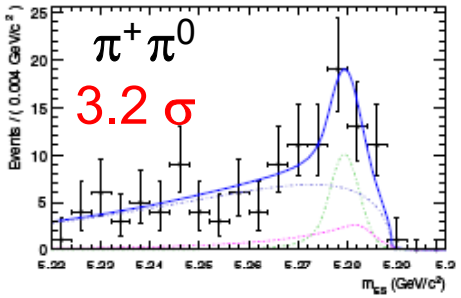
$B^0 \to \omega \gamma$

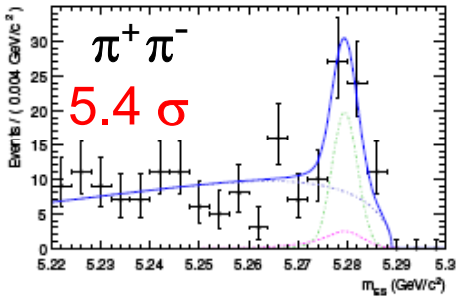
arXiv:0808.1379  423/fb

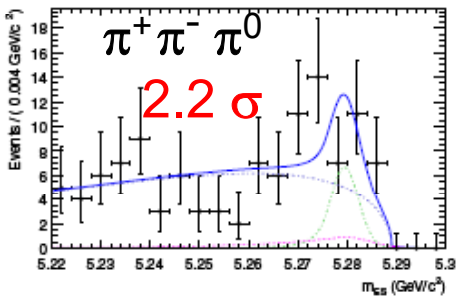
$\rho^+ \to \pi^+ \pi^0$

$\rho^0 \to \pi^+ \pi^-$

$\omega \to \pi^+ \pi^- \pi^0$







Combined significance 6.5 σ

$BF(\text{combined}) = (1.63 \pm {}^{0.30}_{0.28} \pm 0.16)\,10^{-6}$

$|V_{td}/V_{ts}| = 0.233 \pm 0.025 \pm 0.022$

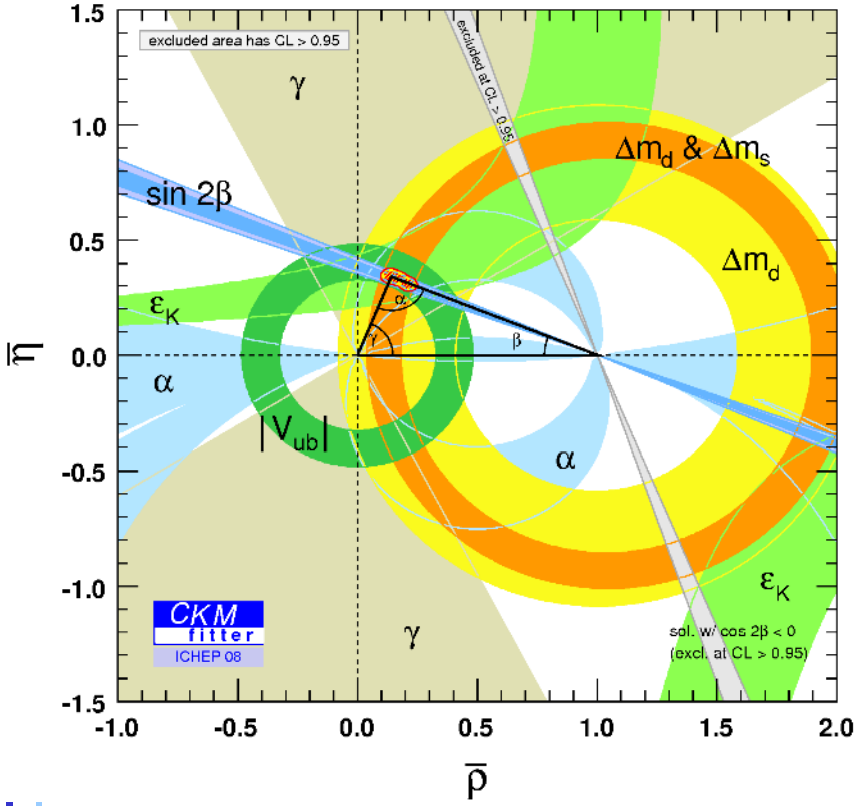
in agreement but not competitive with

$|V_{td}/V_{ts}| = 0.208 \pm 0.002 \pm 0.008$

from $\Delta m(B^0)/\Delta m(B_s)$ and LQCD.

(this topic really belongs into S. Playfer's talk)

Summary



No deviation from the CKM description of quark mixing has been observed. Precision of the agreement between $|V_{us}|$, $|V_{cb}|$, $|V_{ub}|$, $|V_{tb}V_{td}|$, $|V_{td}/V_{ts}|$, the phases of the invariant quartets $V_{ud}V_{ub}^*V_{tb}V_{td}^*$, $V_{td}V_{tb}^*V_{cb}V_{cd}^*$, $V_{ud}V_{ub}^*V_{cb}V_{cd}^*$, and $|V_{ud}|$, $|V_{cd}|$, $|V_{cs}|$, $|V_{ts}V_{tb}|$ is impressive.

CKMfitter 2008: $|V_{us}| = 0.2252 \pm 0.0008$,

$|V_{cb}| = 0.0405 \pm {}^{0.0011}_{0.0008}$,

$|V_{ub}| = 0.0034 \pm 0.0002$,

$\mathrm{Im}(V_{ub}V_{ud}^*V_{cd}V_{cb}^*) = +\,(2.8 \pm {}^{0.2}_{0.4})\,10^{-5}$.

Why is precision important? FutureTheory may reduce # of St.M. parameters

(when preparing this talk, I encountered only one 4 σ discrepancy, the rate of $\tau \to K\nu$ disagrees with that of $K \to \mu\nu$ and lepton universality.)

Honours

Progress of Theoretical Physics, Vol. 49, No. 2, February 1973

CP-Violation in the Renormalizable Theory of Weak Interaction

Makoto KOBAYASHI and Toshihide MASKAWA

Department of Physics, Kyoto University, Kyoto

(Received September 1, 1972)

One spin-½ quartet (p,n,λ,ζ) + H,W

2 L-doublets, 4 R-singlets ⇒ no CPV

2 L-doublets, 1 R-d., 2 R-s. ⇒ CPV

one new scalar field ⇒ CPV

UNITARY SYMMETRY AND LEPTONIC DECAYS

Nicola Cabibbo
CERN, Geneva, Switzerland

(Received 29 April 1963)

PRL 10 (1963) 531

$$J_\mu = \cos\theta \cdot (V+A)_\mu^{\Delta S=0} + \sin\theta \cdot (V+A)_\mu^{\Delta S=1}$$

θ = 0.257 from Γ(K → μν)/Γ(π → μν)

[4]Similar considerations are forwarded in M. Gell-Mann and M. Lévy, Nuovo Cimento 16, 70 **(1960)**

$$GV_\alpha + GV_\alpha^{(\Delta S=1)} = G_\mu \bar{p}\gamma_\nu(n + \varepsilon\Lambda)(1+\varepsilon^2)^{-\frac{1}{2}}$$

$$\varepsilon^2 = .06$$

Next we consider a 6-plet model, another interesting model of CP-violation. Suppose that 6-plet with charges $(Q, Q, Q, Q-1, Q-1, Q-1)$ is decomposed into $SU_{\text{weak}}(2)$ multiplets as $2+2+2$ and $1+1+1+1+1+1$ for left and right components, respectively.

...

$$\begin{pmatrix} \cos\theta_1 & -\sin\theta_1\cos\theta_3 & -\sin\theta_1\sin\theta_3 \\ \sin\theta_1\cos\theta_2 & \cos\theta_1\cos\theta_2\cos\theta_3 - \sin\theta_2\sin\theta_3 e^{i\delta} & \cos\theta_1\cos\theta_2\sin\theta_3 + \sin\theta_2\cos\theta_3 e^{i\delta} \\ \sin\theta_1\sin\theta_2 & \cos\theta_1\sin\theta_2\cos\theta_3 + \cos\theta_2\sin\theta_3 e^{i\delta} & \cos\theta_1\sin\theta_2\sin\theta_3 - \cos\theta_2\sin\theta_3 e^{i\delta} \end{pmatrix}$$

Then, we have CP-violating effects through the interference among these different current components.

$V_{CKM} \not\rightarrow V_{GLCHGWSBIMKM}$

We are very proud of the prize awarded to KM.