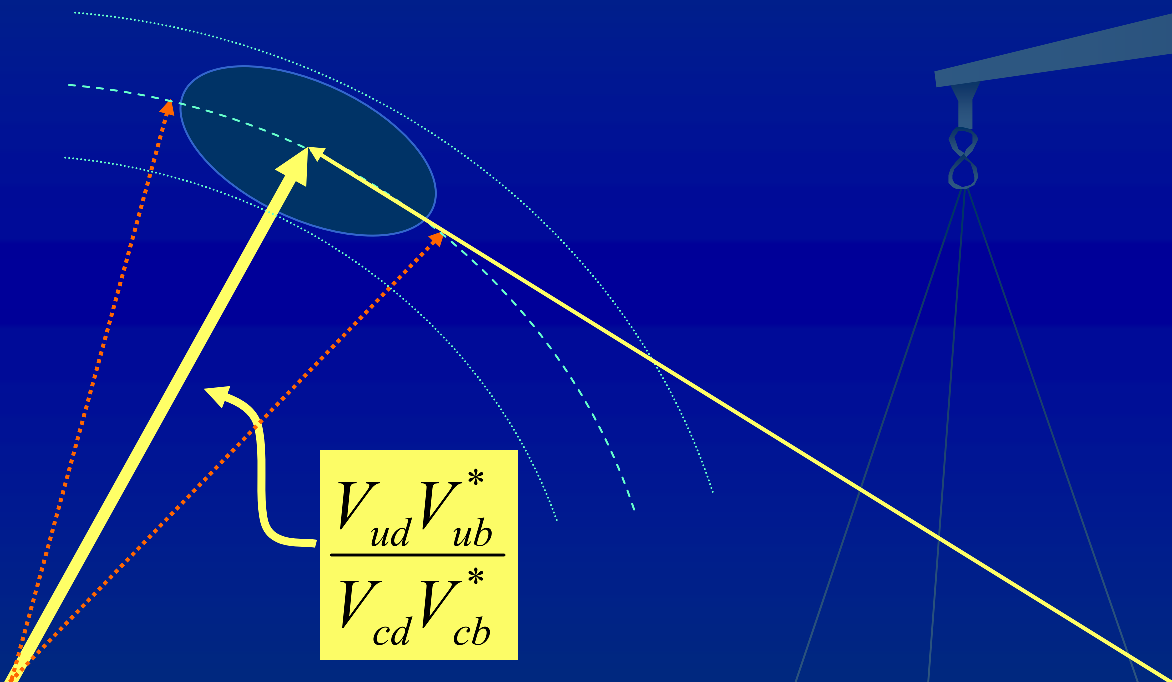
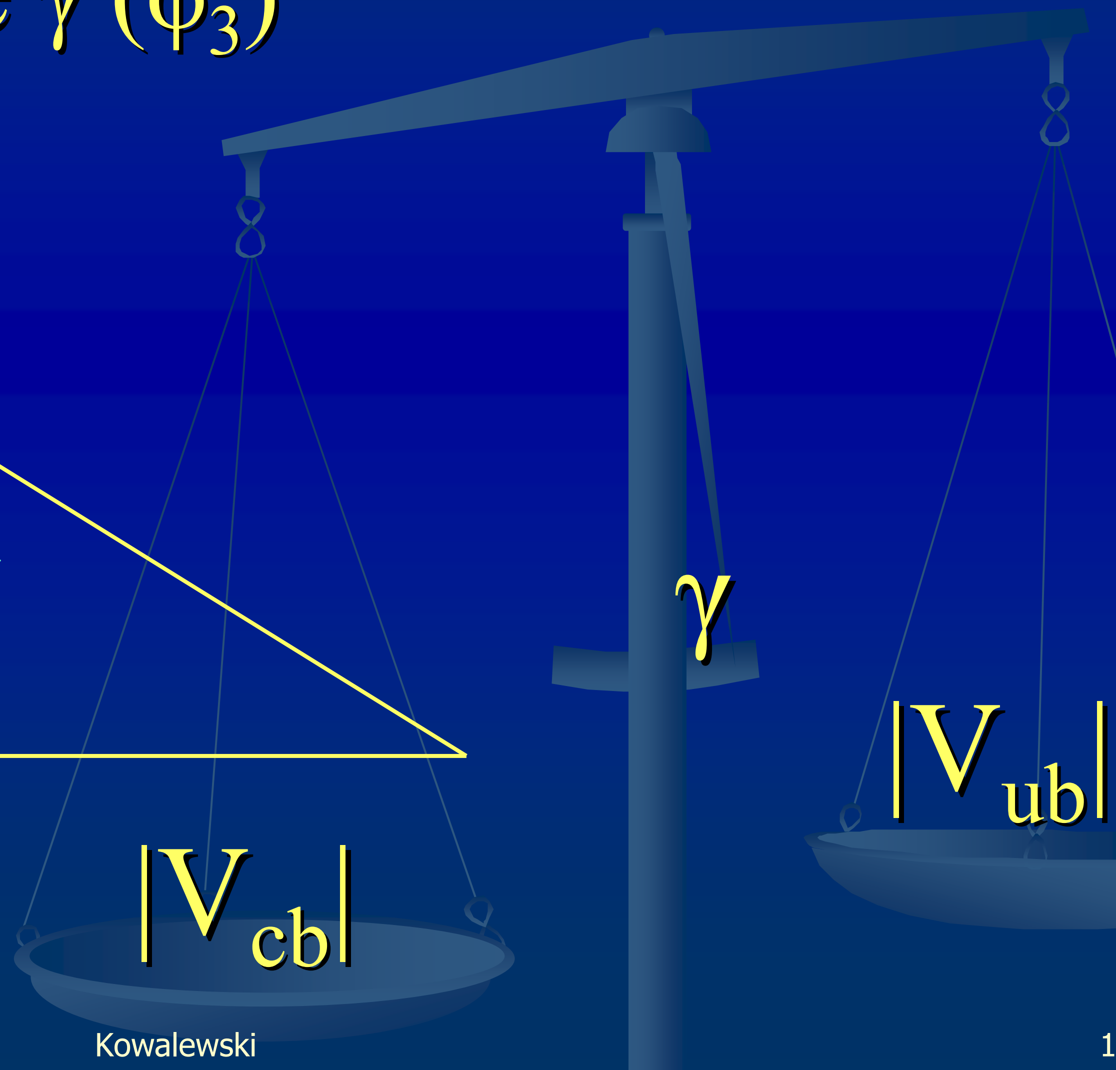
Measuring the apex: $|V_{ub}|$, $|V_{cb}|$ and their relative phase γ (φ_3)



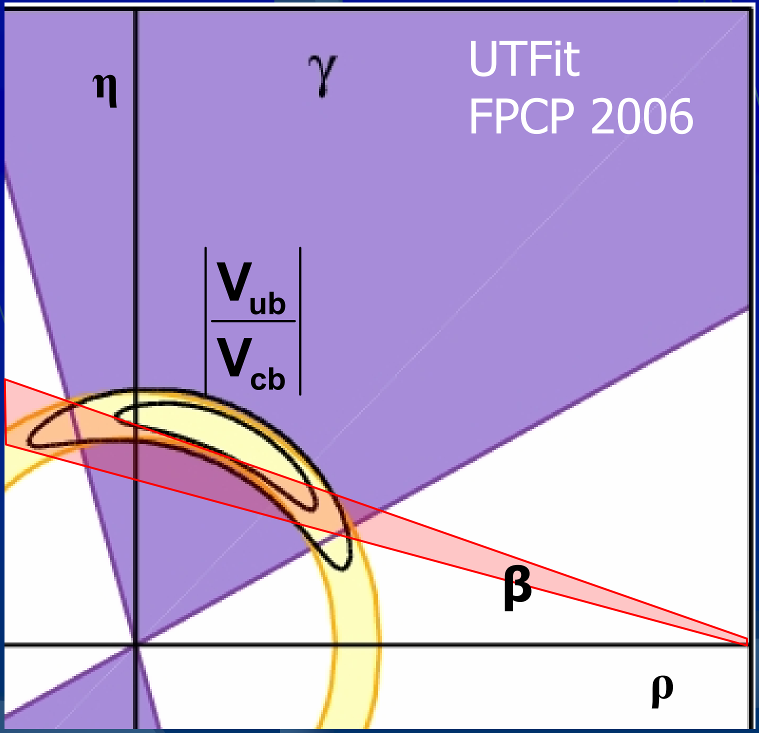


Р. Ковалевски
R. Kowalewski
U. of Victoria
Canada

Motivation

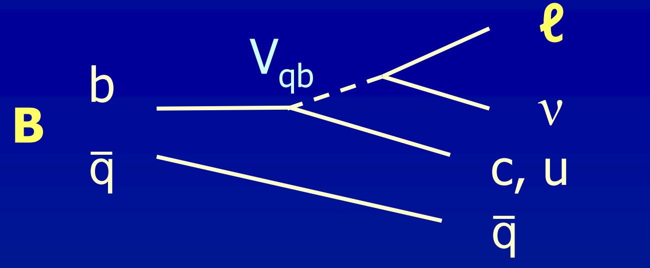
$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & |V_{ts}| & |V_{tb}| \end{pmatrix}$$

- V_{ub} is a key element of the CKM matrix
- 1 graduate student lifetime (~20 years) ago, we didn't know that $V_{ub} \neq 0$: Was the KM mechanism for ~~CP~~ viable?
- Now the precise determination of V_{ub} / V_{cb} provides a benchmark for testing new physics in other processes

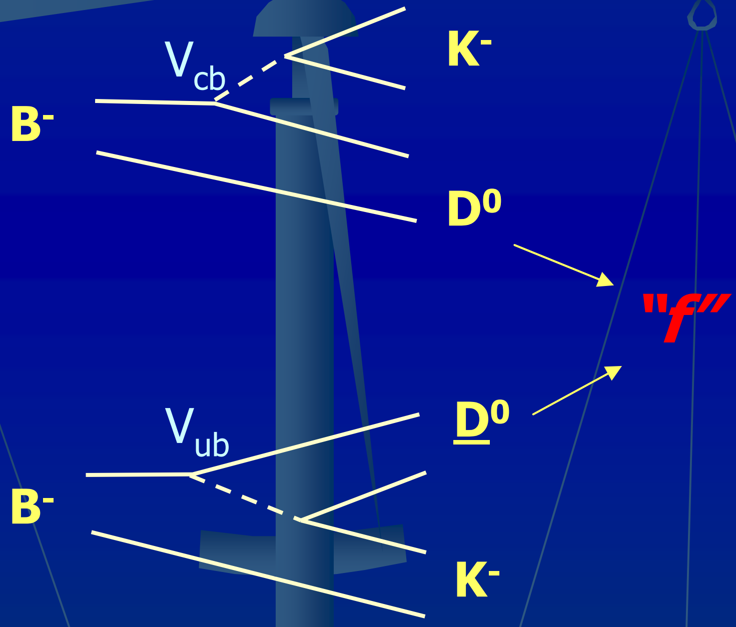


Big trees dominate!

The decay channels used to study $|V_{ub}|$, $|V_{cb}|$ and their relative phase are all dominated by tree diagrams



Lifetime + semileptonic decay determine $|V_{qb}|$

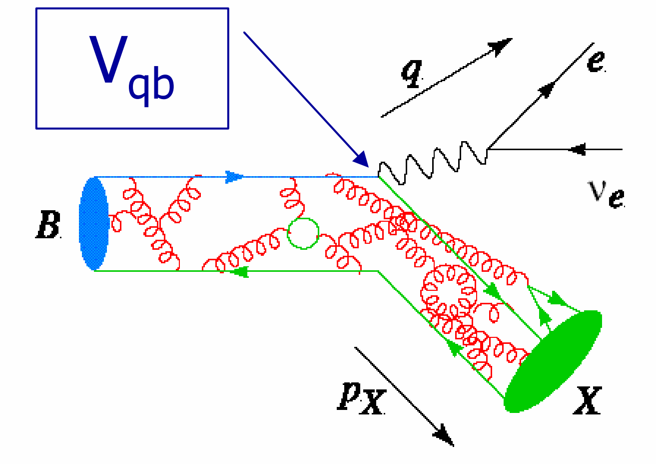


Interference allows phase measurement

$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & |V_{ts}| & |V_{tb}| \end{pmatrix}$$

The magnitudes $|V_{cb}|$ and $|V_{ub}|$

Semileptonic B decay - theory

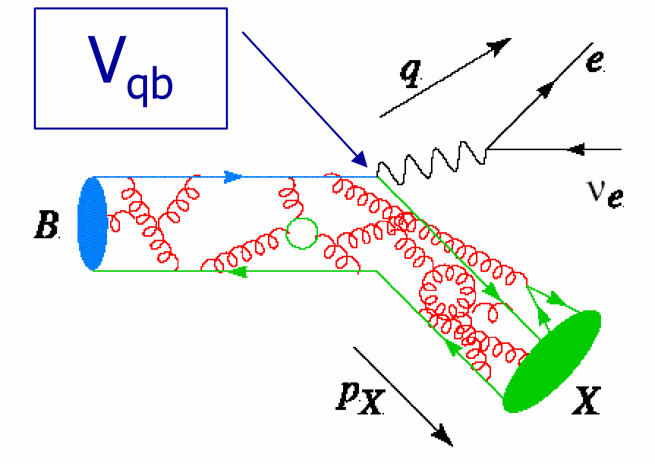


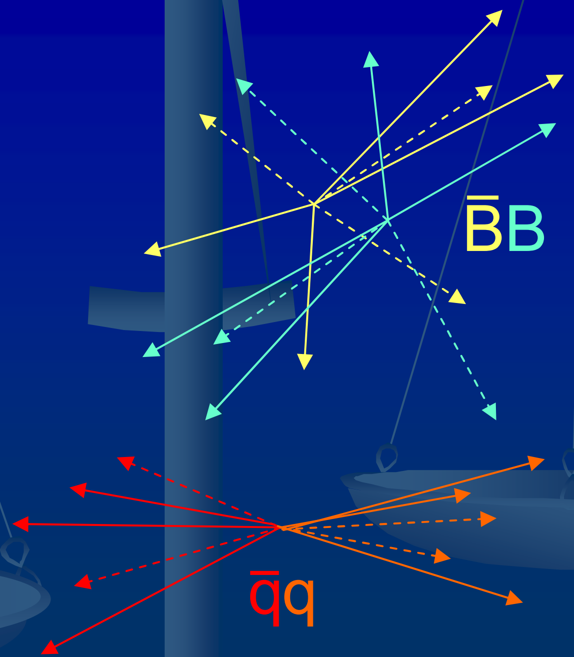
- Large BF, only one hadronic current
- Inclusive decays $b \to q\ell\nu$:
  - Weak quark decay + QCD corrections → OPE in α_s and $1/m_b$
- Exclusive decays $B \to X\ell\nu$:
  - Form factors: need Lattice QCD

These inclusive and exclusive determinations of V_{qb} are ***complementary***

Semileptonic B decay - experiment

- Inclusive decays $b \rightarrow q\ell\nu$:
  - Measure lepton
  - Measure p_{miss} or associated hadrons
- Exclusive decays $B \rightarrow X_q\ell\nu$:
  - Measure lepton and specified hadrons
- Measurements come from $\Upsilon(4S) \rightarrow B\bar{B}$
- Determine non-B contribution using data below $B\bar{B}$ threshold





See talk of Urquijo, S10

$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & |V_{ts}| & |V_{tb}| \end{pmatrix}$$

Inclusive $|V_{cb}|$

Inclusive decay width

- Total decay width for b → cℓν:

$$r = m_c / m_b$$

$$\Gamma = |V_{cb}|^2 \frac{G_F^2 m_b^5}{192\pi^3}(1 + A_{ew}) A^{pert}(r,\mu) \times \left[z_0(r) + \frac{0}{m_b} + z_2\left(r, \frac{\mu_\pi^2}{m_b^2}, \frac{\mu_G^2}{m_b^2}\right) + z_3\left(r, \frac{\rho_D^3}{m_b^3}, \frac{\rho_{LS}^3}{m_b^3}\right) + \ldots \right]$$

free quark decay ~1.014 ~0.908

Perturbative corrections

Non-perturbative power corrections

- Similar expressions for b → uℓν, b → sγ

- Comparison with data relies on quark-hadron duality
  → integrate over "broad" regions of phase space

Low-order moments can be calculated reliably

Global fit for $|V_{cb}|$, m_b…

- Fit predicted moments of inclusive processes $b \to c\ell\nu$ and $b \to s\gamma$ for various cuts on kinematic variables:

$$\left\langle M_x^n \right\rangle_{E_l > E_0} = \tau_B \int_{E_0} M_X^n \, d\Gamma = f_n^x\left(E_0, m_b, m_c, \underbrace{\mu_G^2, \mu_\pi^2, \rho_D^3, \rho_{LS}^3}_{\text{Matrix elements appearing at order } 1/m_b^2 \text{ and } 1/m_b^3}\right)$$

e or γ energy cut

b-quark mass

c-quark mass

Matrix elements appearing at order $1/m_b^2$ and $1/m_b^3$

- Calculations available in "kinetic" and "1S" renormalization schemes

Benson, Bigi, Gambino, Mannel, Uraltsev
(several papers)

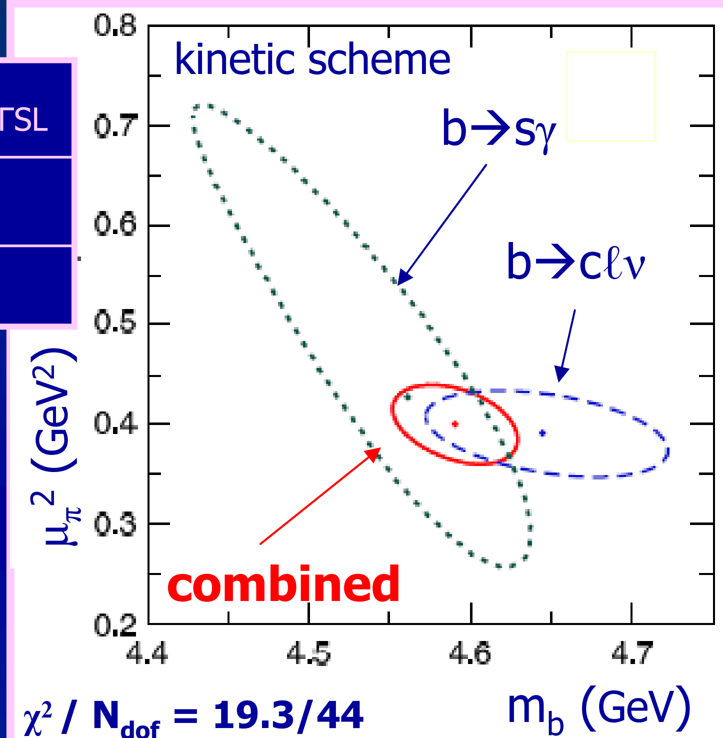
Bauer, Ligeti, Luke, Manohar, Trott
PRD 70:094017 (2004)

- 47 measured moments used from DELPHI, CLEO, BABAR, BELLE, CDF (and, of course, the B lifetime)

Global fit: results

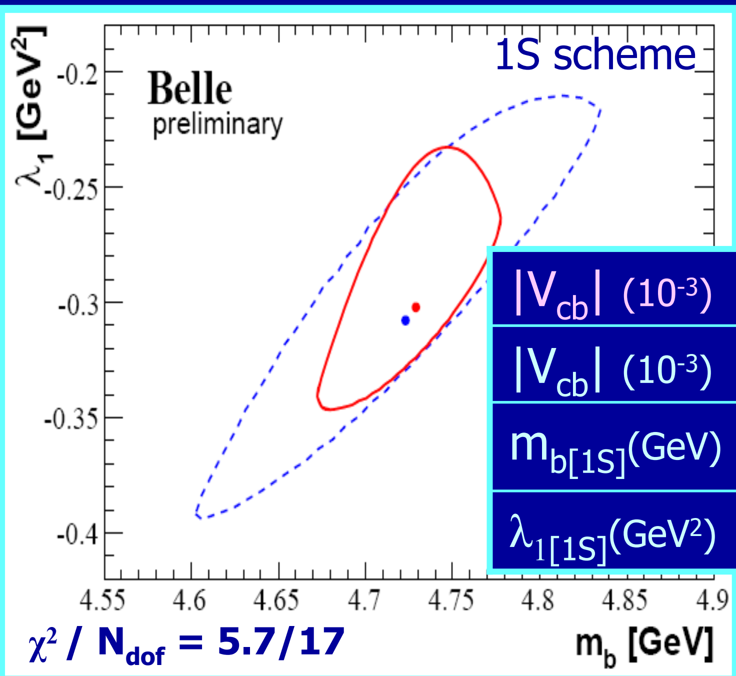
$\lvert V_{cb}\rvert$ (10^{-3})	$41.96 \pm 0.23_{exp} \pm 0.35_{HQE} \pm 0.59_{\Gamma SL}$
$m_{b\,[kin]}$(GeV)	$4.59 \pm 0.025_{exp} \pm 0.030_{HQE}$
$\mu_\pi^{\,2}{}_{[kin]}$(GeV^2)	$0.401 \pm 0.019_{exp} \pm 0.035_{HQE}$

$|V_{cb}|$ determined to <2%
Only $\sin\theta_c$ known better!



$\chi^2 / N_{dof} = 19.3/44$

Buchmüller and Flächer, PRD 73: 073008 (2006)



$\chi^2 / N_{dof} = 5.7/17$

New!

$\lvert V_{cb}\rvert$ (10^{-3})	$42.0 \pm 0.7_{fit} \pm 0.5_{\alpha s} \pm 0.6_{th}$
$\lvert V_{cb}\rvert$ (10^{-3})	$41.5 \pm 0.5_{fit} \pm 0.2\tau_B$
$m_{b[1S]}$(GeV)	$4.73 \pm 0.05_{fit}$
$\lambda_{1[1S]}$(GeV^2)	$-0.30 \pm 0.04_{fit}$

m_b to 1%;
crucial for $|V_{ub}|$

[kin]/[1S] values agree after scheme translation

See talks of Dubitzky, Schwanda, S10

$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & |V_{ts}| & |V_{tb}| \end{pmatrix}$$

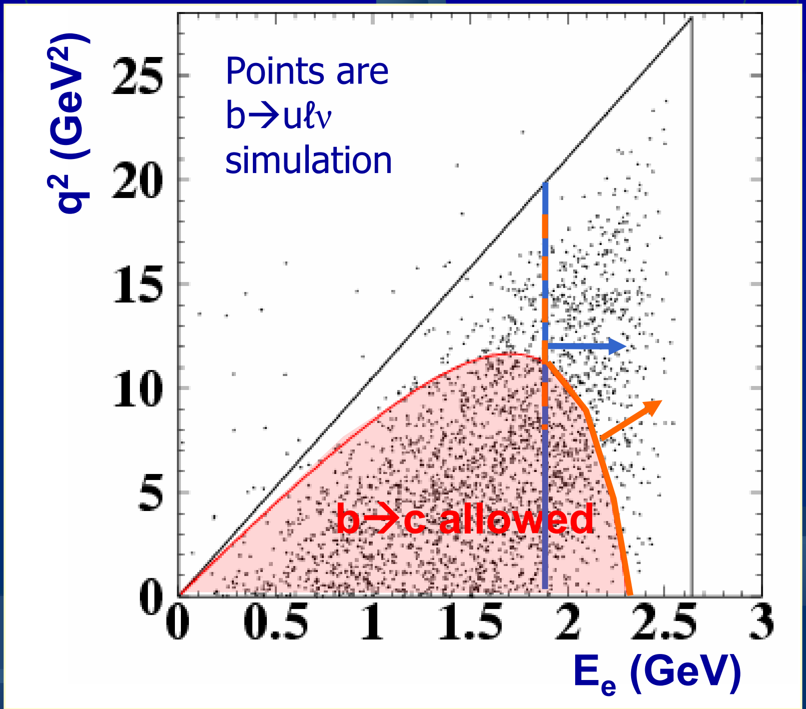
Inclusive $|V_{ub}|$

Strategies for isolating $b \to u \ell \nu$ decays

- Background $b \to c \ell \nu$ rate is 50 times signal
- Restrict kinematics to suppress background: challenge for theory
  - OPE convergence is compromised:
    - Need light-cone distribution (shape) function of b quark
    - Relate $b \to u \ell \nu$ directly to $b \to s \gamma$ (e.g. Lange, Neubert, Paz, JHEP 0510:084, 2005)

- Measure $b \to u$ rate in regions dominated by $b \to c$
  - Theory fine; must fight large uncertainties from background

In all cases sensitivity to m_b^N, N»5

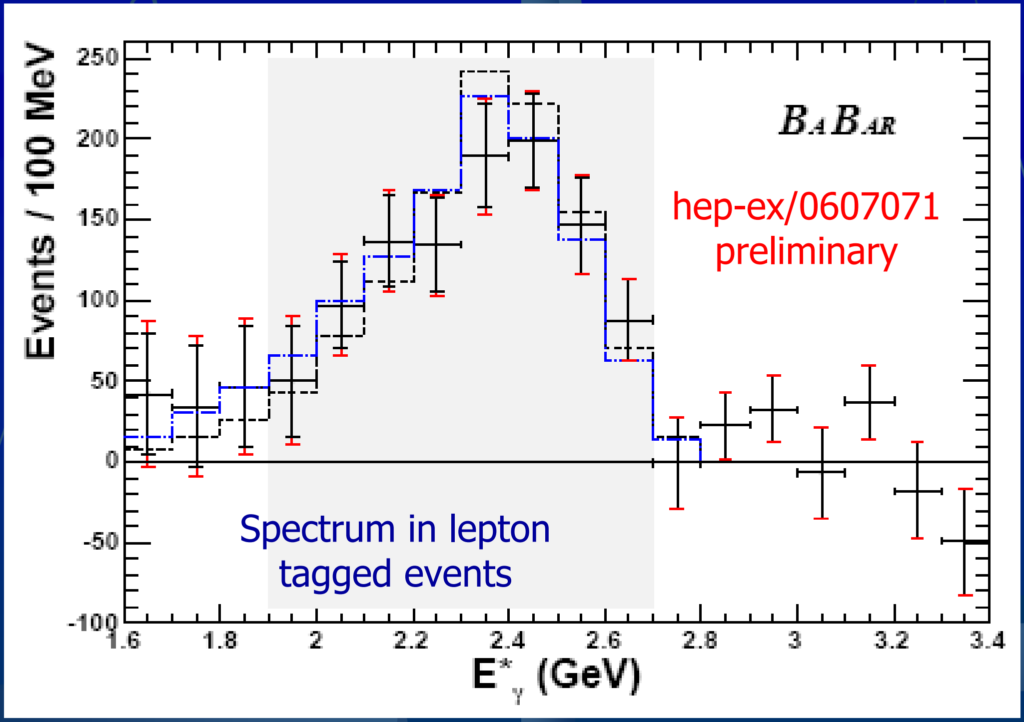


Shape function

- $b \to s\gamma$ spectrum measured by CLEO, Belle, BaBar
- SF moments related to HQE parameters

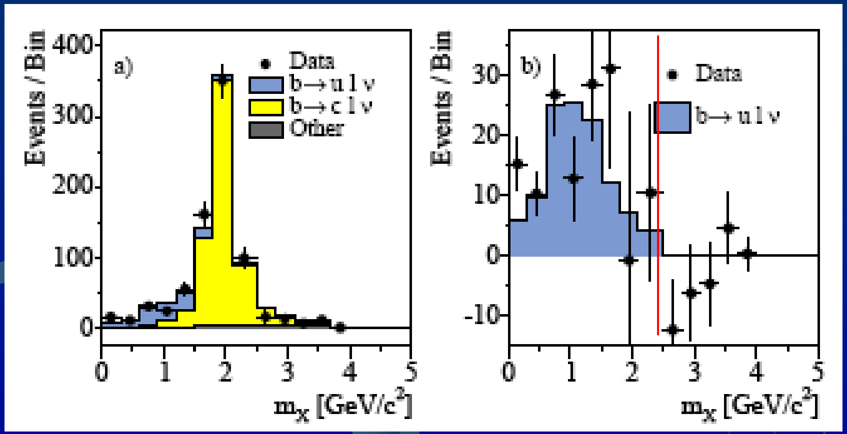
$$\langle E_\gamma \rangle \approx \frac{m_b}{2}, \; \left\langle E_\gamma^2 - \langle E_\gamma \rangle^2 \right\rangle \propto \mu_\pi^2$$

- Subleading shape functions differ in $b \to s\gamma$, $b \to u\ell\nu$



New measurements

BaBar result: PRL 96:221801 (2006)



- Fully reconstruct 1 B meson; study semileptonic decay of other B
- Relate $\int_0^{m_{\max}} \frac{d\Gamma_{b\to u}}{dm_X} dm_X$ to $\int_{E_{\min}}^{m_B/2} \frac{d\Gamma_{b\to s\gamma}}{dE_\gamma} W(E_\gamma, E_{\min}) dE_\gamma$

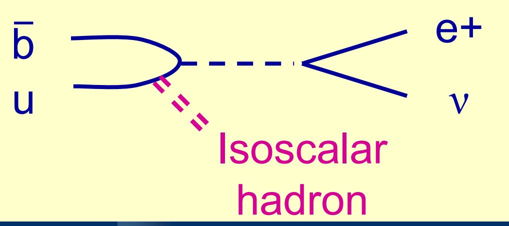
  $|V_{ub}|=(4.43 \pm 0.38 \pm 0.25 \pm 0.29)\ 10^{-3}$
- Measure up to m_X < 2.5 GeV

  $|V_{ub}|=(3.84 \pm 0.70 \pm 0.30 \pm 0.10)\ 10^{-3}$

Theory errors are small

Will improve – only 88×10^6 $B\bar{B}$ used so far

CLEO limit Weak Annihilation contributions:
$\Gamma_{WA} / \Gamma_{b\to u} < 7.4\%$ (90% CL) PRL 96:121801 (2006)



Theory calculations

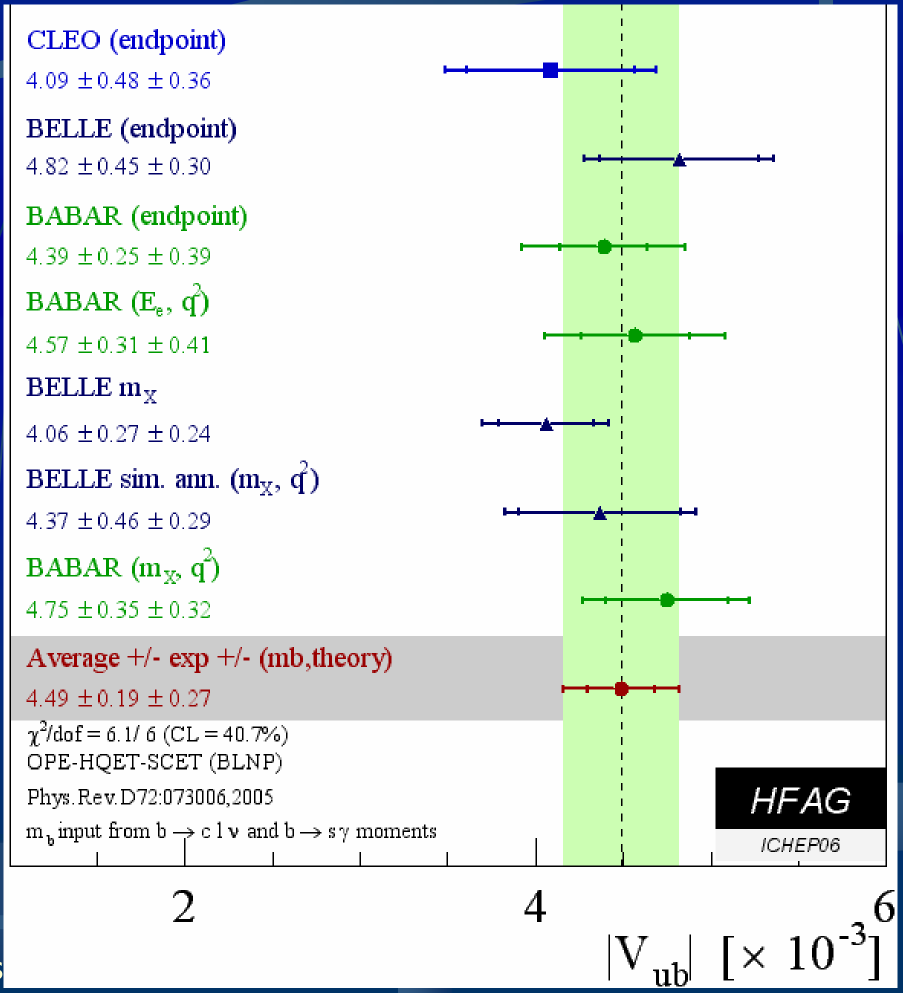
- Two sets of calculations in use for $b \rightarrow s\gamma$ and $b \rightarrow u\ell\nu$
  - Bosch, Lange, Neubert, Paz (BLNP): 3-scale OPE based on HQET, SCET — PRD 72:073006 (2005)
  - Andersen, Gardi (DGE): parton-level calculation, only m_b and Λ_{QCD} input — JHEP 0601:097 (2006)
- Both provide good description of data; give similar results
- Bauer, Ligeti, Luke (BLL): $|V_{ub}|$ using m_X-q^2 cuts — PRD 64:113004 (2001)

Determination of $|V_{ub}|$

$$|V_{ub}| = (4.49 \pm 0.19 \pm 0.27) \times 10^{-3} \text{ (BLNP)}$$

Major progress since last ICHEP

- Good C.L. = 41%
- Error budget (in %; total 7.3) :
  $\left.\begin{array}{l} \pm 2.2_{stat}\ \pm 2.8_{exp}\ \pm 1.9_{WA} \\ \pm 1.9_{b2c\ model}\ \pm 1.6_{b2u\ model} \end{array}\right\} \sim \text{exp}$
  $\pm 4.2_{HQ\ param}\ \pm 3.8_{sub\ SF}\ \} \sim \text{theory}$
- DGE: $(4.46 \pm 0.20 \pm 0.20) \times 10^{-3}$
  C.L. = 12%
- BLL m_X-q^2: $(5.02 \pm 0.26 \pm 0.37) \times 10^{-3}$
  C.L. = 77%
- Many measurements use small fraction of current data samples.
  Aggressive target for 2008 is 5%



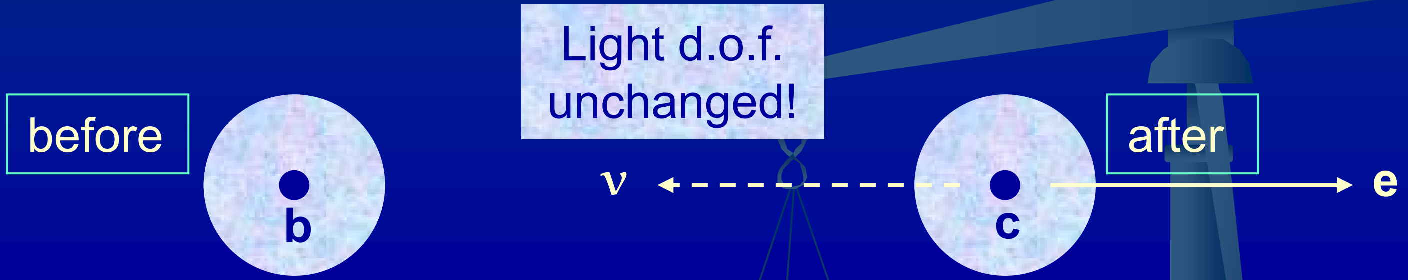
See talk of
Lopes Pegna, S10

$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & |V_{ts}| & |V_{tb}| \end{pmatrix}$$

Exclusive $|V_{cb}|$

Exclusive $b\to c\ell\nu$ decays

- Heavy-to-heavy transition; HQ symmetry applies → unique, universal FF, unit normalization at zero recoil



$$\frac{d\Gamma\left(B\to D^{*}\ell\nu\right)}{dw}=\frac{G_F^2\left|V_{cb}\right|^2}{48\pi^3}\left(\mathrm{F}(w)\right)^2\mathrm{G}(w)$$

form factors

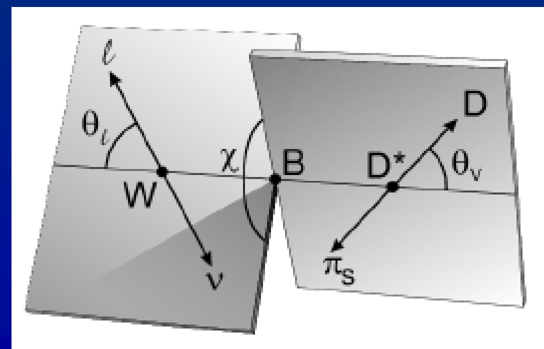
phase space

D^* boost in the B rest frame

$$w\equiv\frac{m_B^2+m_{D*}^2-q^2}{2m_Bm_{D*}};\ 1<w<1.504$$

$B \rightarrow D^{*}\ell\nu$ form factor

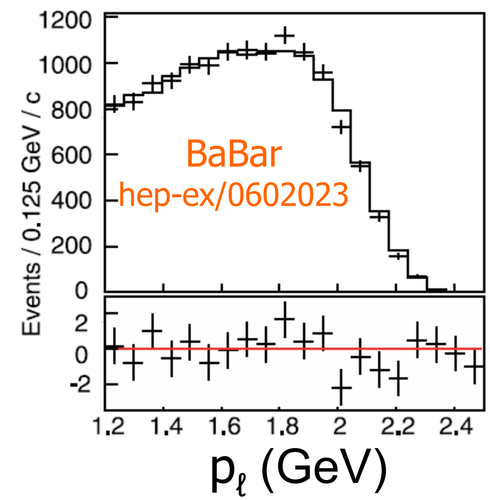
- 3 non-trivial form factors; 4 observables: w and 3 angles
  HQET-params:
  $\rho^2 = -d\mathbf{F}/dw\,|_{w=1}$,
  $R_1 \sim V/A_1$ and
  $R_2 \sim A_2/A_1$

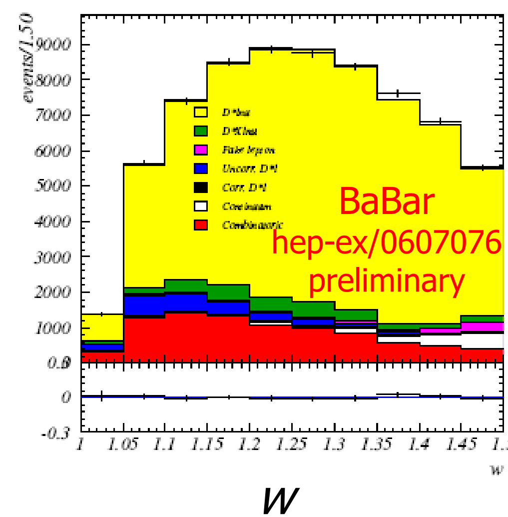


- Two measurements from BaBar; averaged values:

  $\rho^2 = 1.179 \pm 0.048 \pm 0.028$
  $R_1 = 1.417 \pm 0.061 \pm 0.044$
  $R_2 = 0.836 \pm 0.037 \pm 0.022$

  $\mathbf{F}(1)|V_{cb}| = (34.68 \pm 0.32 \pm 1.15)\times 10^{-3}$
  $BF(B^0 \rightarrow D^{*+}\ell^-\nu) = 4.84 \pm 0.39\%$





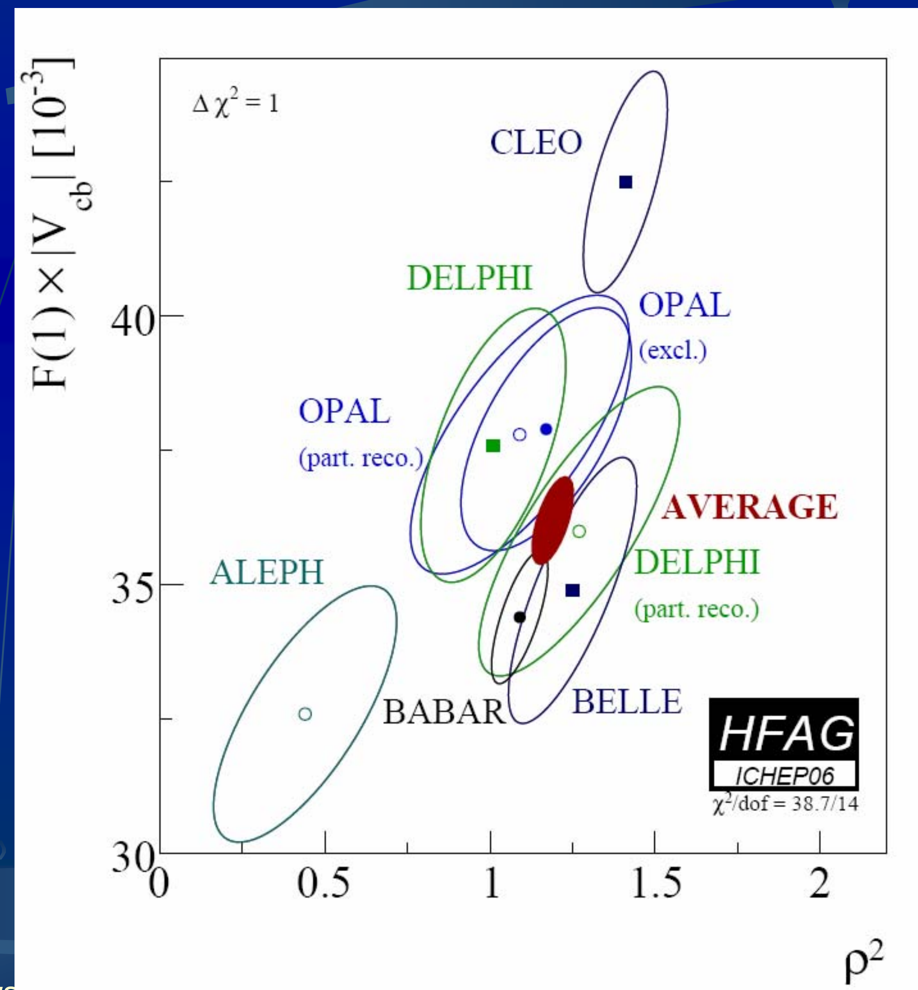
$|V_{cb}|$ from $B \to D^{(*)}\ell\nu$

- New HFAG average including updated form-factors
  $F(1)|V_{cb}| = (36.2 \pm 0.8)\times 10^{-3}$
- Using $F(1) = 0.919^{+0.030}_{-0.035}$

  (Quenched LQCD, PRD 66:014503 (2002))

  $$|V_{cb}| = \left(39.4 \pm 0.87^{+1.56}_{-1.24}\right)\times 10^{-3}$$

  (inclusive: $|V_{cb}|=(42.0\pm 0.7)\times 10^{-3}$)



- Work needed on both experiment and theory to reach the precision of the inclusive determination
- Similar measurements on $B\to D\ell^-\nu$ are harder; in progress

See talks of Dubitzky,
Schwanda, S10

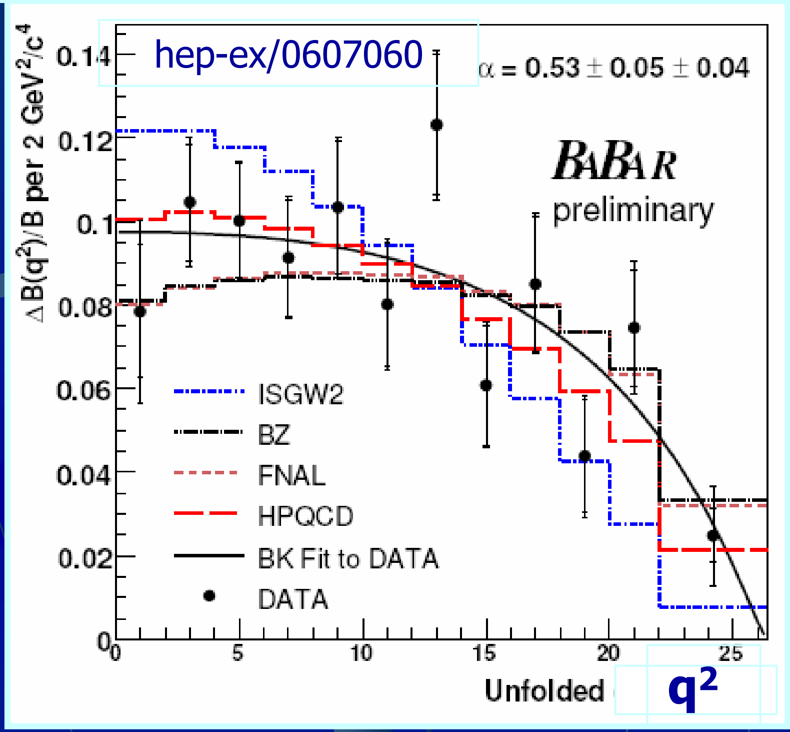
$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & |V_{ts}| & |V_{tb}| \end{pmatrix}$$

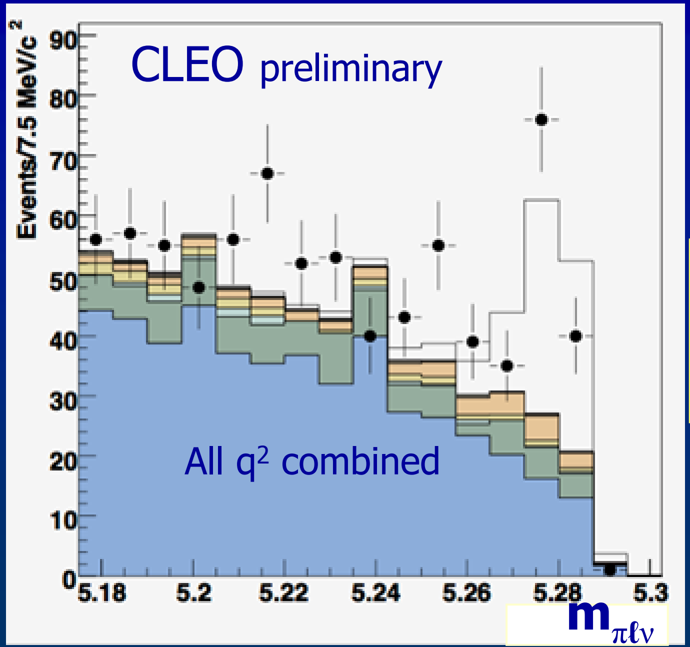
Exclusive $|V_{ub}|$

$B \rightarrow \pi \ell \nu$

$$\mathbf{BF(B \to \pi \ell \nu) = (1.44 \pm 0.08 \pm 0.10) \times 10^{-4}}$$
$$\mathbf{\Delta BF(q^2 > 16\ GeV^2) = (0.37 \pm 0.04 \pm 0.03) \times 10^{-4}}$$
$$\boldsymbol{\alpha_{BK}} \mathbf{= 0.53 \pm 0.05 \pm 0.04}$$

- New BaBar $B^0 \rightarrow \pi^- \ell^+ \nu$
  - High statistics ν-reco method
  - Significantly improved precision
  - ISGW2 model: C.L. = 0.07%
  - Data consistent with Lattice QCD and Becirevic-Kaidalov



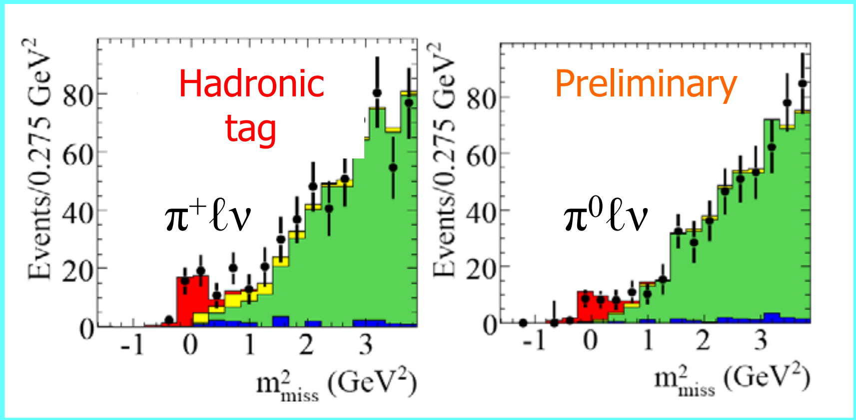


- New CLEO $B^0 \rightarrow \pi^-/\rho^- \ell^+ \nu$ preliminary
  - Good quality ν-reco

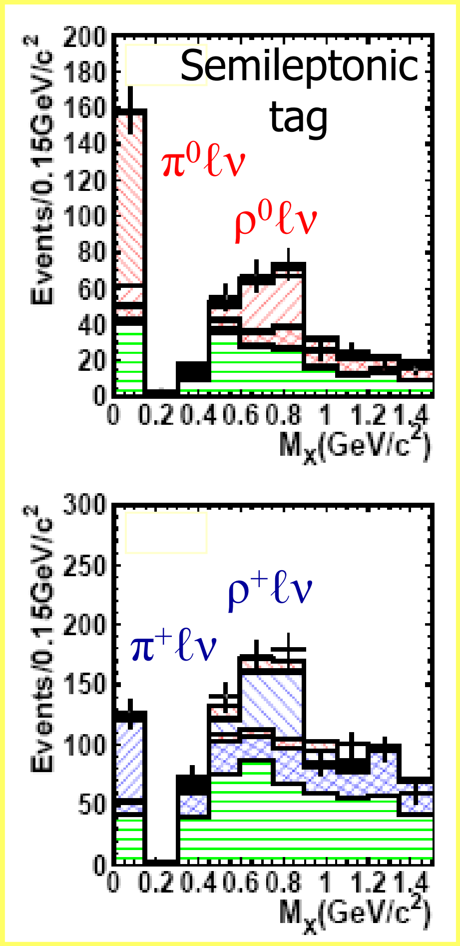
$$\mathbf{BF(B \to \pi \ell \nu) = (1.37 \pm 0.16 \pm 0.13) \times 10^{-4}}$$
$$\mathbf{\Delta BF(q^2 > 16\ GeV^2) = (0.40 \pm 0.08 \pm 0.05) \times 10^{-4}}$$
$$\mathbf{BF(B \to \rho \ell \nu) = (2.91 \pm 0.38 \pm 0.38) \times 10^{-4}}$$

$B \to \pi \ell \nu$ with low background

- Reconstruct (tag) one B in hadronic or semileptonic decay
- Compare what's left with signal



BaBar →
211 fb^{-1}



← Belle
253 fb^{-1}

BF (10^{-4})	Belle hep-ex/0604024	BaBar hep-ex/0607089
$\pi^+\ell\nu$ (s.l. tag)	$1.38 \pm 0.19 \pm 0.14$	$1.12 \pm 0.25 \pm 0.10$
$\pi^0\ell\nu$ (s.l. tag) $\times 2\tau_0/\tau_+$	$1.43 \pm 0.26 \pm 0.16$	$1.35 \pm 0.33 \pm 0.19$
$\pi^+\ell\nu$ (had tag)	$1.49 \pm 0.26 \pm 0.06$	$1.07 \pm 0.27 \pm 0.19$
$\pi^0\ell\nu$ (had tag) $\times 2\tau_0/\tau_+$	$1.60 \pm 0.32 \pm 0.11$	$1.52 \pm 0.41 \pm 0.20$
$\rho^0\ell\nu$ / $\eta\ell\nu$	$1.33 \pm 0.23 \pm 0.18$	$0.84 \pm 0.27 \pm 0.21$
$\rho^+\ell\nu$ / $\eta'\ell\nu$	$2.17 \pm 0.54 \pm 0.32$	<1.3

$|V_{ub}|$ from $B \to \pi\ell\nu$

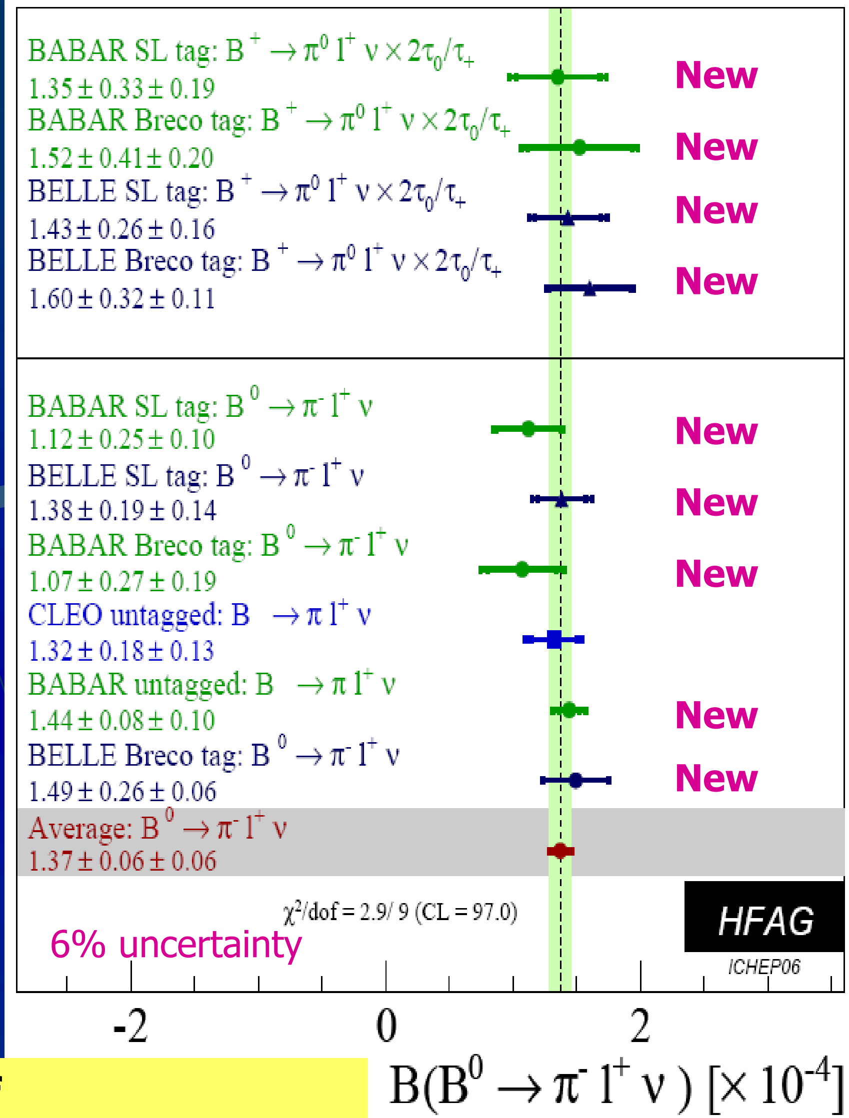
- Averages of tagged and untagged methods are comparable

For $|V_{ub}|$:

- Lattice QCD: $q^2>16$ GeV^2
- Light-cone sum rules: $q^2<16$ GeV^2

- FF normalization errors dominate; task for theory, CLEO-c

(inclusive: $|V_{ub}|=(4.49\pm0.34)\times10^{-3}$



FF calc	Vub [10^{-3}]	FF norm (ps^{-1})	Ref
Ball-Zwicky	$3.38 \pm 0.12\ ^{+0.56}_{-0.37}$	5.44 ± 1.43	PRD 71:014015 (2005)
HPQCD	$3.93 \pm 0.26\ ^{+0.59}_{-0.41}$	1.46 ± 0.35	PRD 73:074502 (2006)
FNAL	$3.51 \pm 0.23\ ^{+0.61}_{-0.40}$	1.83 ± 0.50	hep-lat/0409116
APE	$3.54 \pm 0.23\ ^{+1.36}_{-0.63}$	1.80 ± 0.86	Nucl. Phys. B619:565 (2000)

Experimental error on $|V_{ub}|$ ~ 6%

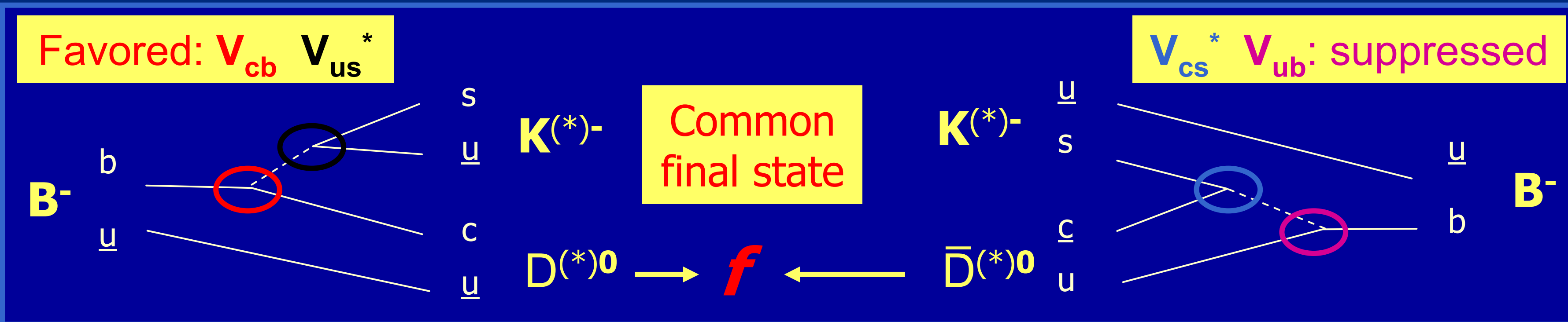
See talks of Marchiori, Krokovny, S8

$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & |V_{ts}| & |V_{tb}| \end{pmatrix}$$

The phase: γ (φ_3)

The relative phase γ (φ_3)

Interference between tree-level decays; theoretically clean



$$\frac{A\left(B^- \to \bar{D}^0 K^-\right)}{A\left(B^- \to D^0 K^-\right)} = r_B e^{i\delta_B} e^{-i\gamma}$$

Parameters: γ,
(r_B, δ_B) per mode

Three methods for exploiting interference (choice of D^0 decay modes):

- Gronau, London, Wyler (GLW): Use CP eigenstates of $D^{(*)0}$ decay, e.g. $D^0 \to K_s\pi^0$, $D^0 \to \pi^+\pi^-$
- Atwood, Dunietz, Soni (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \to K^+\pi^-$
- Giri, Grossman, Soffer, Zupan (GGSZ) / Belle: Use Dalitz plot analysis of 3-body D^0 decays, e.g. $K_s\,\pi^+\pi^-$

GLW-based analyses

- Measure asymmetry between B^+/B^- for CP even/odd D decays

$$\mathcal{A}_{CP\pm} = \frac{\Gamma(B^- \to D_\pm K^-) - \Gamma(B^+ \to D_\pm K^+)}{\Gamma(B^- \to D_\pm K^-) + \Gamma(B^+ \to D_\pm K^+)} = \frac{\pm 2 r_B \sin\delta_B \sin\gamma}{1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma}$$

8-fold ambiguity on γ

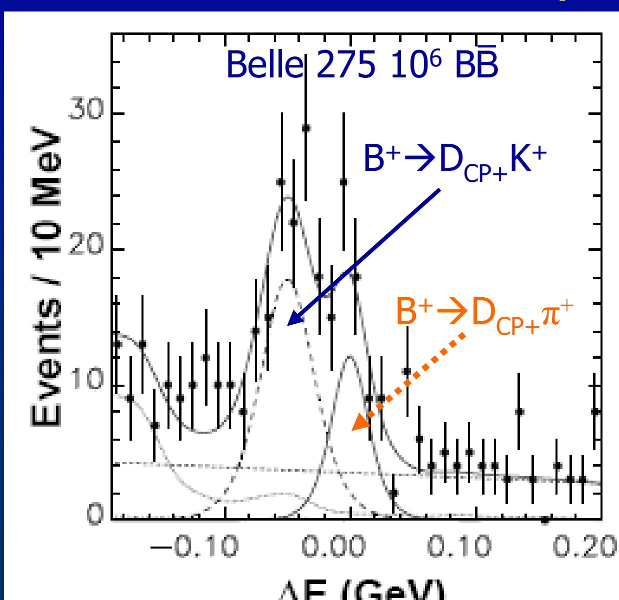
and the fractional decay rates to CP eigenstates:

$$\mathcal{R}_{CP\pm} = \frac{\Gamma(B^- \to D_\pm K^-) + \Gamma(B^+ \to D_\pm K^+)}{\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to \overline{D}^0 K^+)} = 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma$$

Hard to disentangle r_B from γ and δ_B

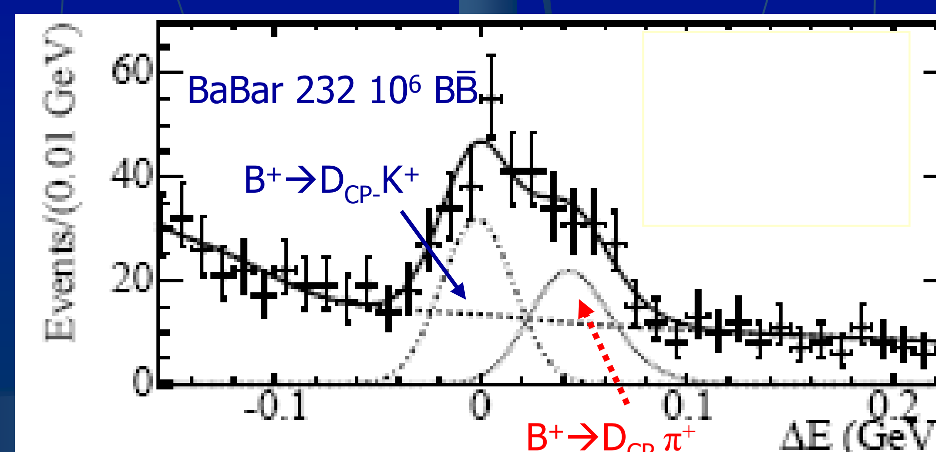
Recent results: Belle (PRD 73:051106, 2006), BaBar (PRD 73: 051105, 2006)

Signals seen in CP-even and CP-odd D decays



CP-even D^0 modes

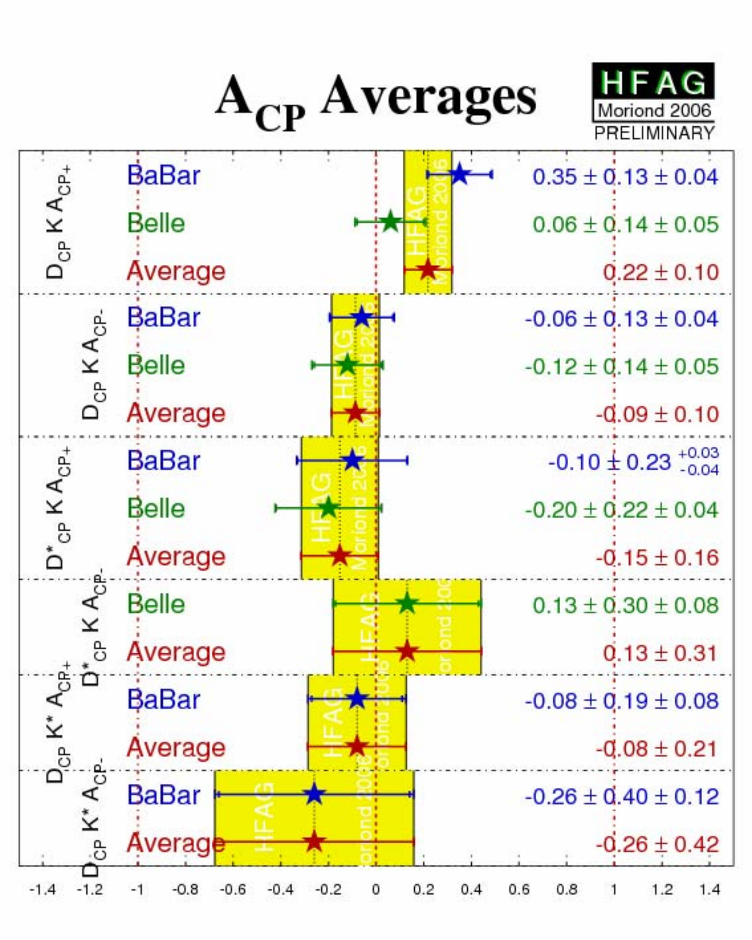
CP-odd D^0 modes



Similar measurements exist in $B^+ \to D^{*0} K^+$

XXXIII INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

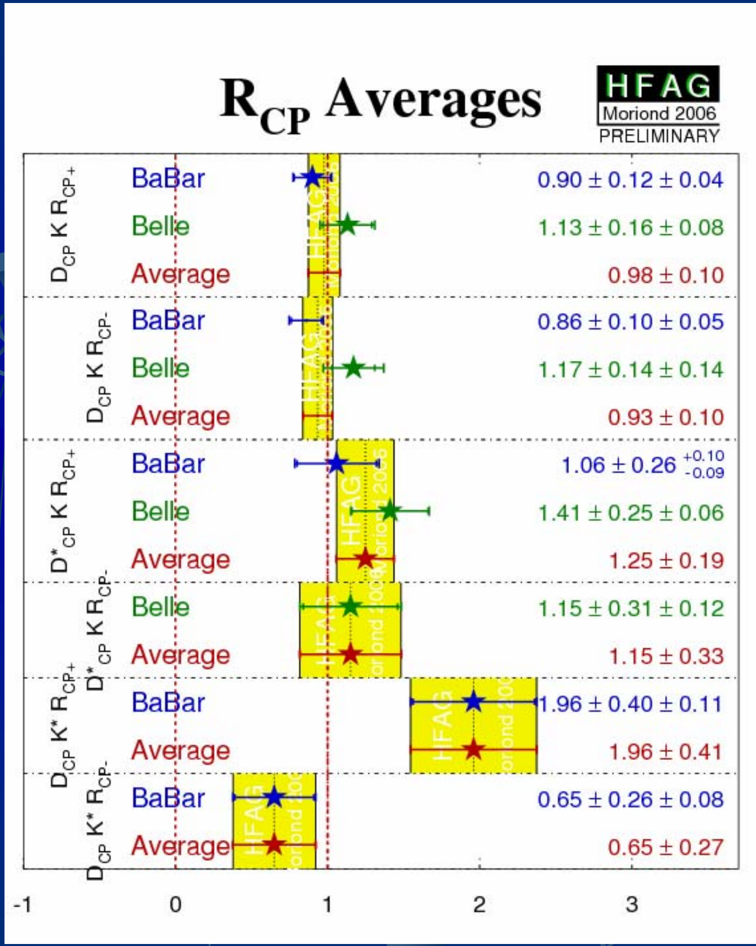
GLW averages



D_{CP} K

D^*_{CP} K

D_{CP} K*



Implications for r_B and γ discussed later

ADS-based analyses

- Use DCS decays to reach same final state, e.g.

favored	suppressed
$B^- \to D^0 K^- \oplus D^0 \to K^+ (n\pi)$	
$B^- \to \overline{D}^0 K^- \oplus \overline{D}^0 \to K^+ (n\pi)$	
suppressed	favored

Small product BF but comparable amplitudes → large potential asymmetry

Additional parameters r_D and δ_D

$$\frac{A\left(B^- \to \overline{D}\left[K^+\pi^-\right]K^-\right)}{A\left(B^- \to D\left[K^+\pi^-\right]K^-\right)} = r_B e^{i\delta_B} e^{-i\gamma} + r_D e^{-i\delta_D}$$

$$\mathcal{A}_{ADS} = \frac{\Gamma\left(B^- \to \left[K^+\pi^-\right]K^-\right) - \Gamma\left(B^+ \to \left[K^-\pi^+\right]K^+\right)}{\Gamma\left(B^- \to \left[K^+\pi^-\right]K^-\right) + \Gamma\left(B^+ \to \left[K^-\pi^+\right]K^+\right)} = \frac{2 r_B r_D \sin\left(\delta_B + \delta_D\right)\sin\gamma}{\mathcal{R}_{ADS}}$$

$$\mathcal{R}_{ADS} = \frac{\Gamma\left(B^- \to \left[K^+\pi^-\right]K^-\right) + \Gamma\left(B^+ \to \left[K^-\pi^+\right]K^+\right)}{\Gamma\left(B^- \to \left[K^-\pi^+\right]K^-\right) + \Gamma\left(B^+ \to \left[K^+\pi^-\right]K^+\right)} = r_B^2 + r_D^2 + 2 r_B r_D \cos\left(\delta_B + \delta_D\right)\cos\gamma$$

Direct dependence

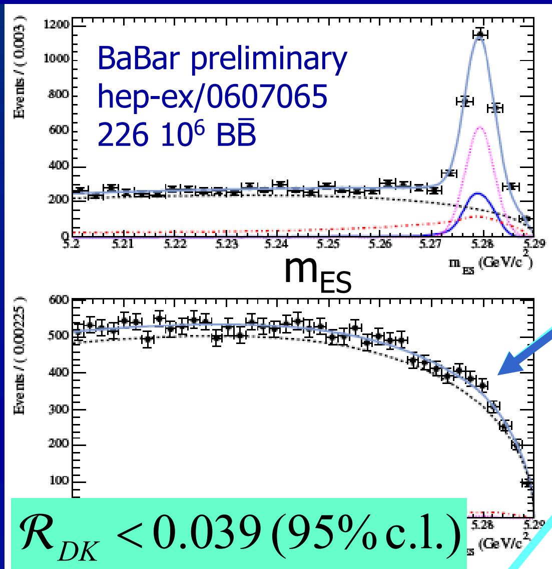
DCSD charm;
r_D (Kπ)= 0.0603 ± 0.0025

Modes D^*K and DK^* also used

$D^{*0} \to D^0\pi$ and $D^{*0} \to D^0\gamma$ have opposite CP

ADS results

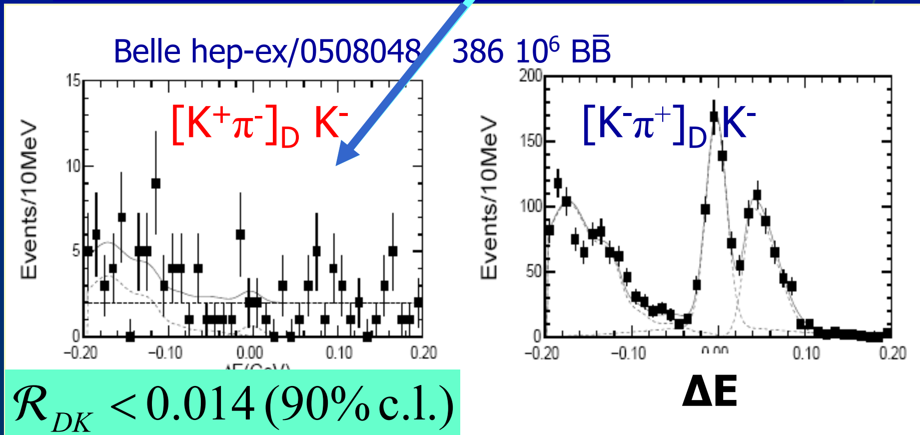
New BaBar result in $[K^+\pi^-\pi^0]_D K^-$



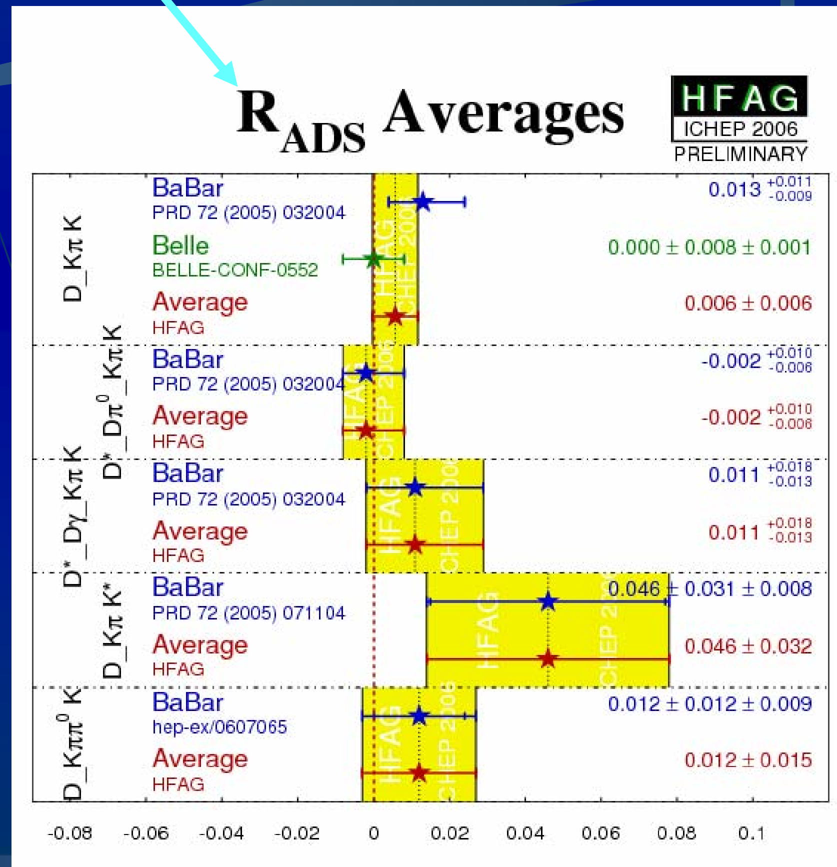
$\mathcal{R}_{DK} < 0.039\,(95\%\,\text{c.l.})$

No signal yet in suppressed modes

Belle result in $[K^+\pi^-]_D K^-$



$\mathcal{R}_{DK} < 0.014\,(90\%\,\text{c.l.})$



Implications for r_B and γ discussed later

Dalitz analyses

- Measure B⁺/B⁻ asymmetry across Dalitz plot

decay

$$B^\pm \to \left[K_s \pi^+ \pi^-\right]_D K^\pm$$

amplitude

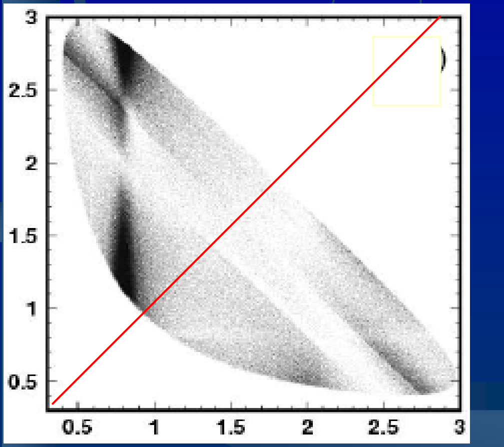
$$A_\pm = f\left(m_+^2, m_-^2\right) + r_B e^{\pm i\gamma} e^{i\delta_B} f\left(m_-^2, m_+^2\right)$$

$$m_\pm^2 \Rightarrow m^2\left(K_s \pi^\pm\right)$$

Mirror symmetry between D^0 and $\bar{D}^0$ Dalitz plots

Sensitivity to γ in interference term

Determine f in flavor-tagged $D^{*+} \to D^0 \pi^+$ decays

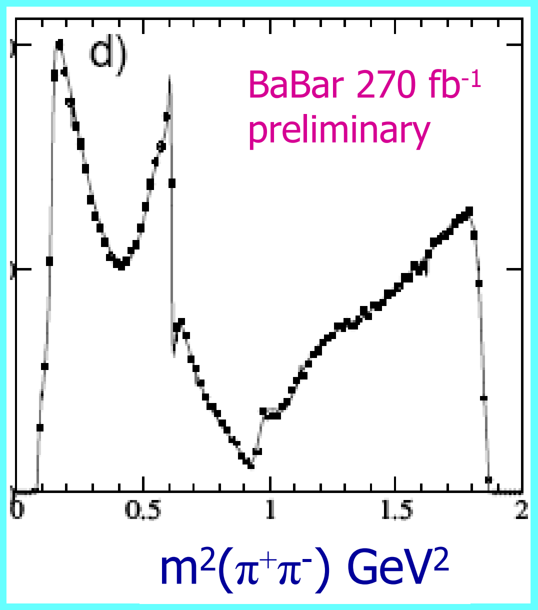


- Includes GLW ($D^0 \to K_s \rho^0$, CP eigenstate) and ADS ($D^0 \to K^{*+}\pi^-$, DCS 2-body decay) regions

2-fold ambiguity on γ: $(\gamma, \delta) \to (\gamma+\pi, \delta+\pi)$

Dalitz model for $K_s\pi^+\pi^-$

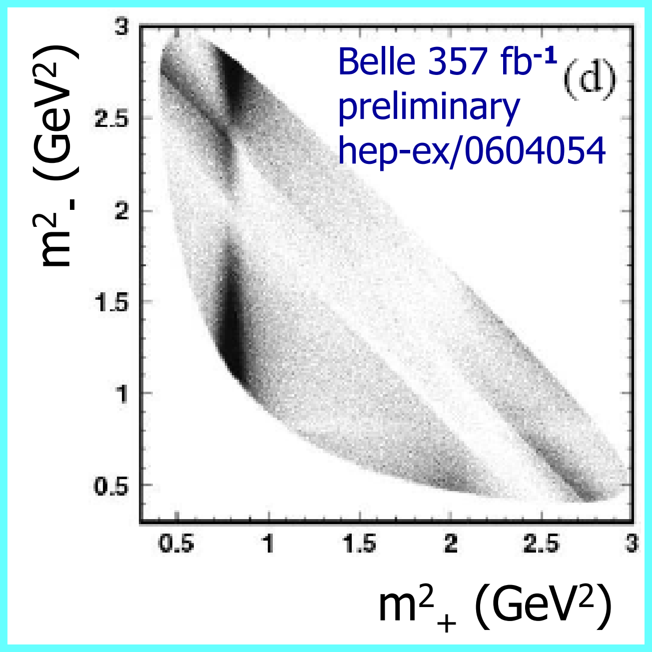
- Select $D^{*+} \rightarrow [K_s\pi^+\pi^-]\pi^+$ from $e^+e^- \rightarrow c\bar{c}$; ~4 10^5 events
- Fit to coherent sum of 15-16 Breit-Wigner amplitudes plus a non-resonant term



Excellent fits obtained

Main contributors:

- $K^{*-}(892)\ \pi^+$
- $K_s\ \rho^0$
- $K^{*0}(1430)\ \pi^-$
- $K^{*-}(892)\ \pi^+$
- non/broad resonant

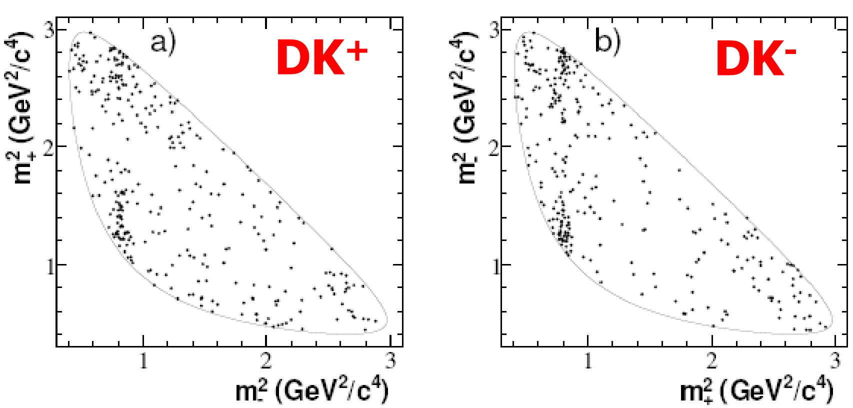


Improved modeling (e.g. K-matrix formulation) under study

Model-independent approach (GGSZ) using CP-tagged D^0 studied by Bondar, Poluektov in hep-ph/0510246

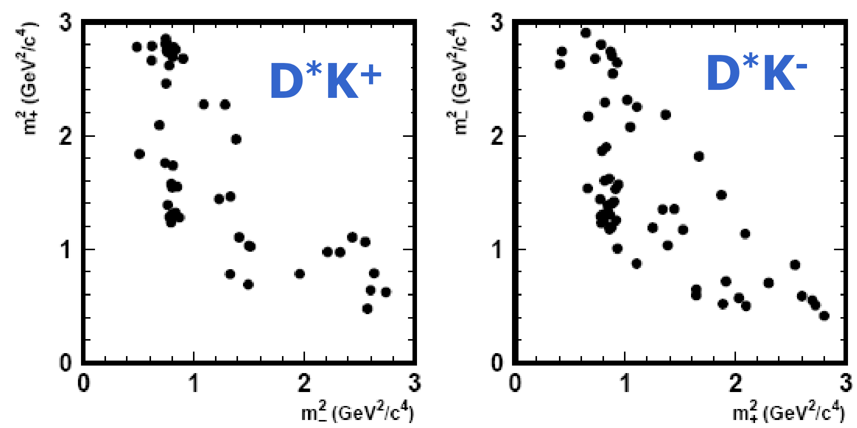
Dalitz plots

- Plots shown are representative; both experiments have analyzed DK, D*K and DK* decays



$347\ 10^6\ B\bar{B}$

BaBar preliminary

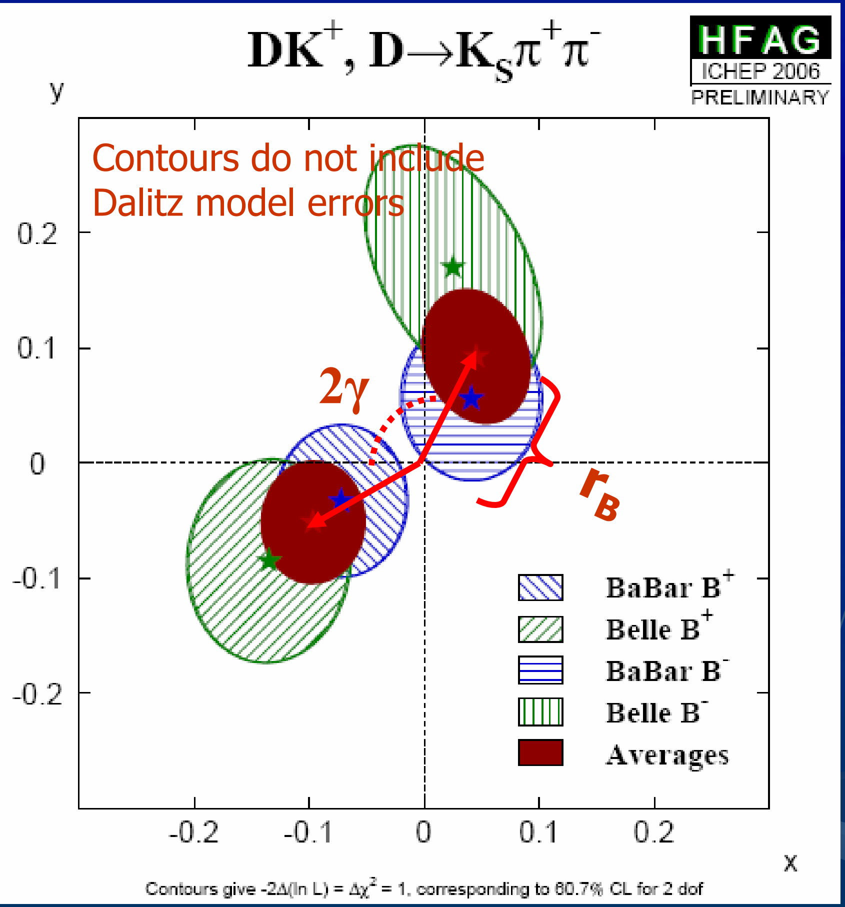


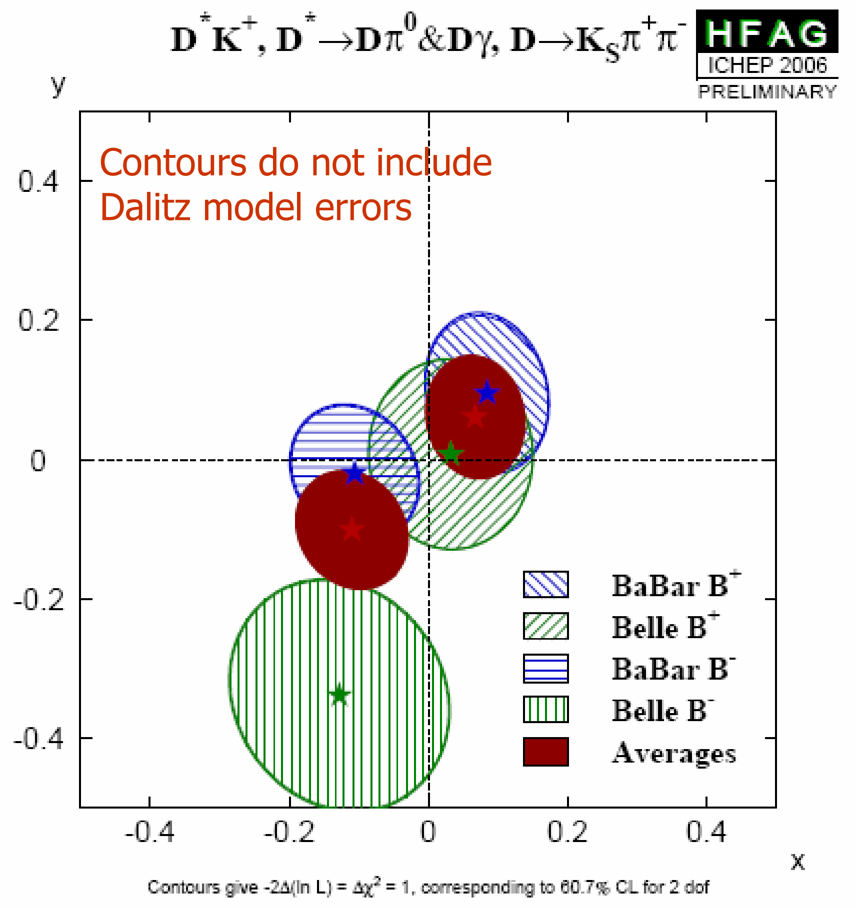
$386\ 10^6\ B\bar{B}$

Belle hep-ex/0604054

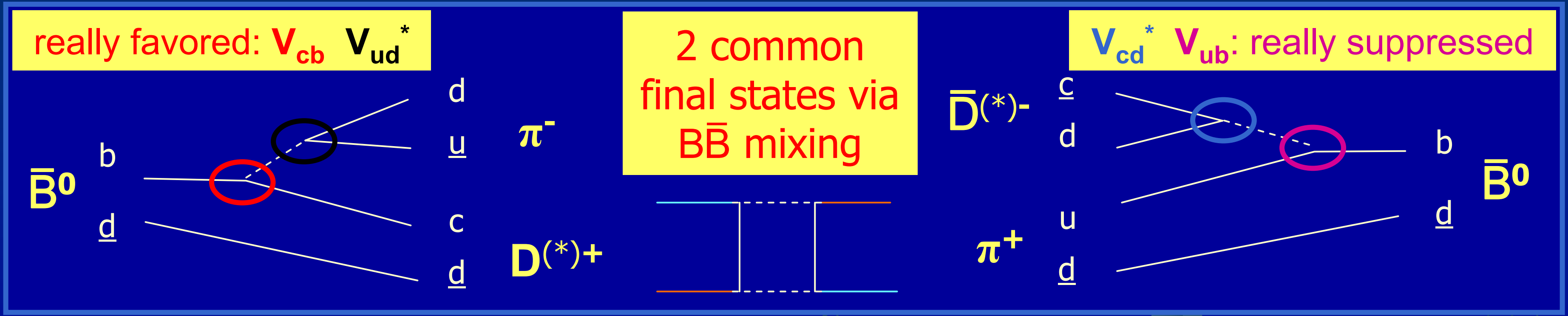
Results on γ

- HFAG averages for $x_\pm = r_B \cos(\delta_B \pm \gamma)$, $y_\pm = r_B \sin(\delta_B \pm \gamma)$
- UTfit find $\gamma = 78 \pm 30°$ based on $B^- \to D^{(*)} K^{(*)-}$ decays
- Note: σ_γ depends significantly on the value of r_B





sin(2β+γ)



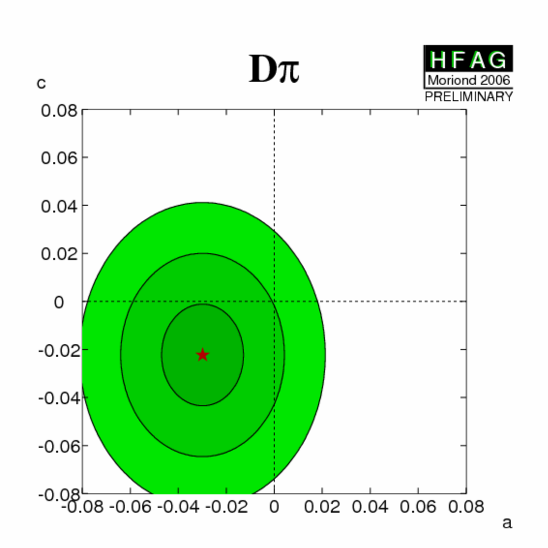
$$\frac{A_{\text{suppressed}}}{A_{\text{favored}}} = r_B e^{i\delta_B} e^{-i(2\beta+\gamma)}$$

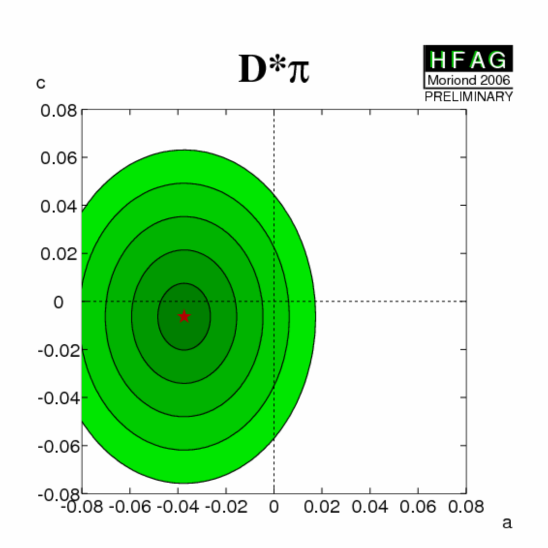
Time-dependent effect (due to B^0-$\bar{B}^0$ mixing)

Parameters: γ, 2β
(r, δ_B) per mode

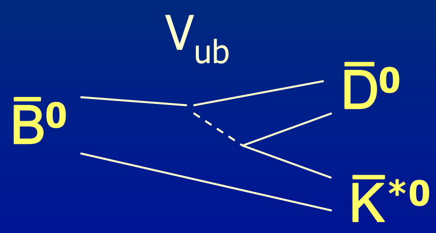
Large BF but small r_B (<2%)
→ small CP asymmetry

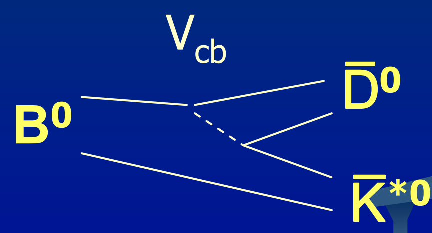
r_B must be estimated from $B^0 \rightarrow D_s^+\pi^-$ using SU(3)



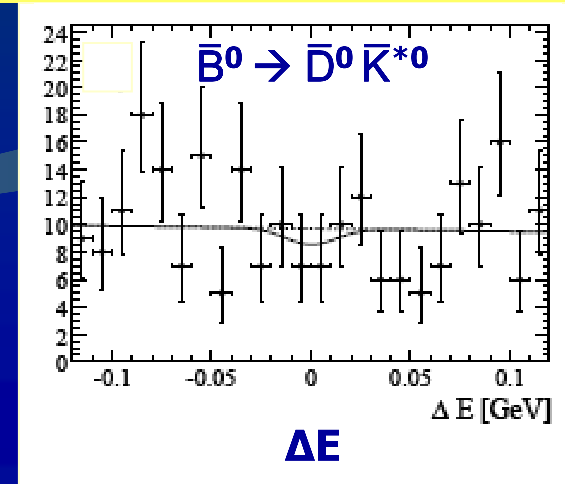


$B^0 \rightarrow D^0 K^0$ feasibility study





BaBar hep-ex/0604016, soon in PRD



- Interference of $\bar{B}^0 \rightarrow \bar{D}^0 \bar{K}^0$ with $\bar{B}^0 \rightarrow B^0 \rightarrow \bar{D}^0 K^0$ (K^0 and $\bar{K}^0$ mix)
- Determine r_{DK^*} in related decay $\bar{B}^0 \rightarrow \bar{D}^0 \bar{K}^{*0}$
- BaBar find no signal: $\mathbf{r_{DK^*}} < 0.4$ @90% c.l.
- This mode may be harder to use for $\sin(2\beta+\gamma)$ than predicted; implications for LHC-b

Related measurements

Nice ideas, nice work, but not much impact yet for γ

$r_{D\pi}$ from $B^0 \rightarrow D_s^{(*)}\pi^-$, SU(3)

BaBar hep-ex/0604012, 226 10^6 $B\bar{B}$

$$\left.\begin{array}{l} BF\left(B \to D_s^+\pi^-\right) = 1.3 \pm 0.3 \pm 0.2 \\ BF\left(B \to D_s^{*+}\pi^-\right) = 2.8 \pm 0.6 \pm 0.5 \\ BF\left(B \to D_s^+K^-\right) = 2.5 \pm 0.4 \pm 0.4 \\ BF\left(B \to D_s^{*+}K^-\right) = 2.0 \pm 0.5 \pm 0.4 \end{array}\right\} \times 10^{-5}$$

$$\Rightarrow \left.\begin{array}{l} r_{D\pi} = 1.3 \pm 0.2 \pm 0.1 \\ r_{D^*\pi} = 1.9 \pm 0.2 \pm 0.2 \end{array}\right\} \times 10^{-2}$$

preliminary

$B^0 \rightarrow D_s\, a_{0,2}$

BaBar PRD D73 \:071103 (2006)

$$\left.\begin{array}{l} BF\left(B \to D_s^+a_0^-\right) < 1.9 \\ BF\left(B \to D_s^{*+}a_0^-\right) < 3.6 \\ BF\left(B \to D_s^+a_2^-\right) < 19 \\ BF\left(B \to D_s^{*+}a_2^-\right) < 20 \end{array}\right\} \times 10^{-5}, 90\%\ \text{c.l.}$$

226 10^6 $B\bar{B}$

$B^0 \rightarrow \bar{D}^0 K^+ \pi^-$

BaBar PRL 96:011803 (2006)

BaBar show that $B \rightarrow \bar{D}^0 K^+\pi^-$ not promising for measuring γ

$B \rightarrow D^*D^*$

BaBar PRD 73:112004 (2006)

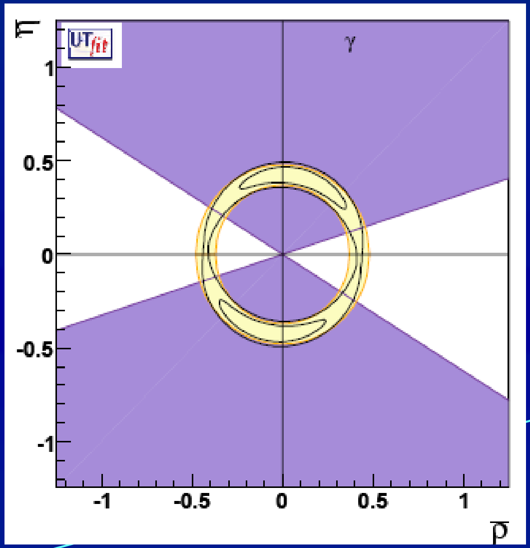
BF and charge asymmetries measured for all $B \rightarrow D^{(*)}D^{(*)}$ modes; provides input for $\sin(2\beta+\gamma)$ from $B^0 \rightarrow D^{(*)+}D^{(*)-}$ time-dependent asymmetries

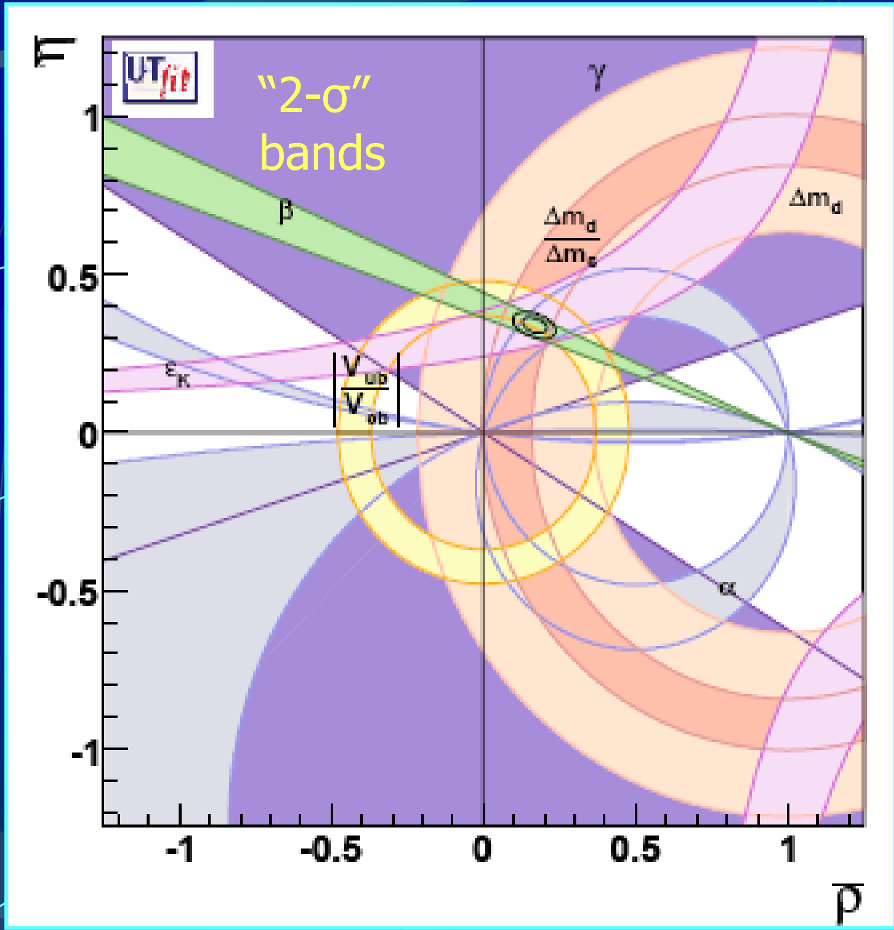
See talks of Vagnoni, T'Jampens, S8

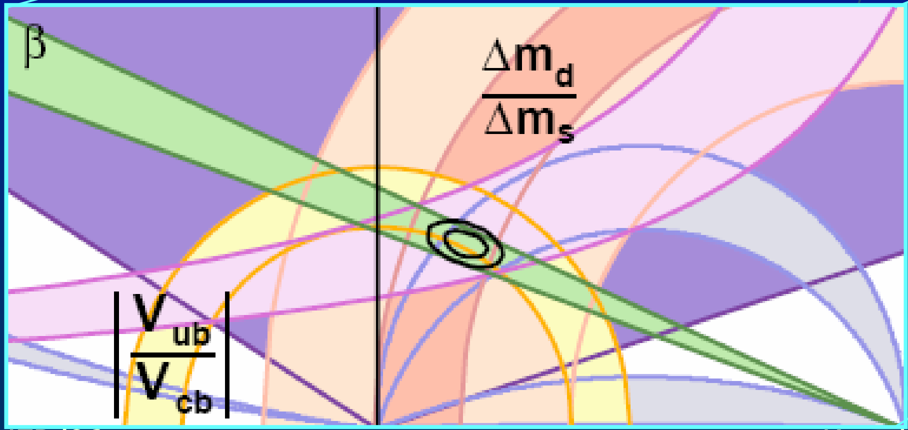
Current status of UT

Tree-level determination: information on phase γ (φ_3) not yet constraining

All constraints: compatible with SM, but tension exists between $\sin 2\beta$ and $|V_{ub}/V_{cb}|$







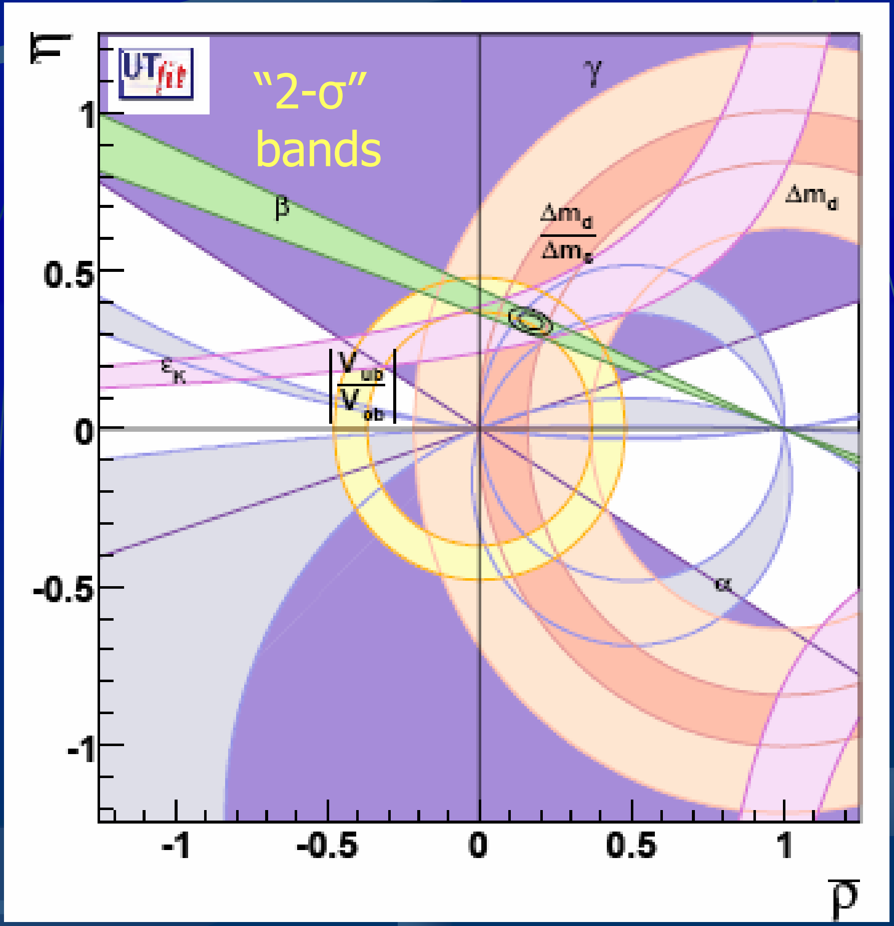
Summary

- Today:

$$|V_{cb}| = (42.0 \pm 0.23 \pm 0.69) \times 10^{-3}$$
$$|V_{ub}| = (4.49 \pm 0.19 \pm 0.27) \times 10^{-3}$$
$$\gamma(\varphi_3) = 78 \pm 30°$$

- What to look for in 2008:
  - 2 ab^{-1} from the B factories (>doubling of data sample)
  - error on $|V_{ub}/V_{cb}|$ of ~5%
  - error on γ: ~10-15° ? (r_B …)
  - LHC-b will have initial data

- The heavy flavor program will restrict the space in which theories for the new physics to be seen at LHC can operate

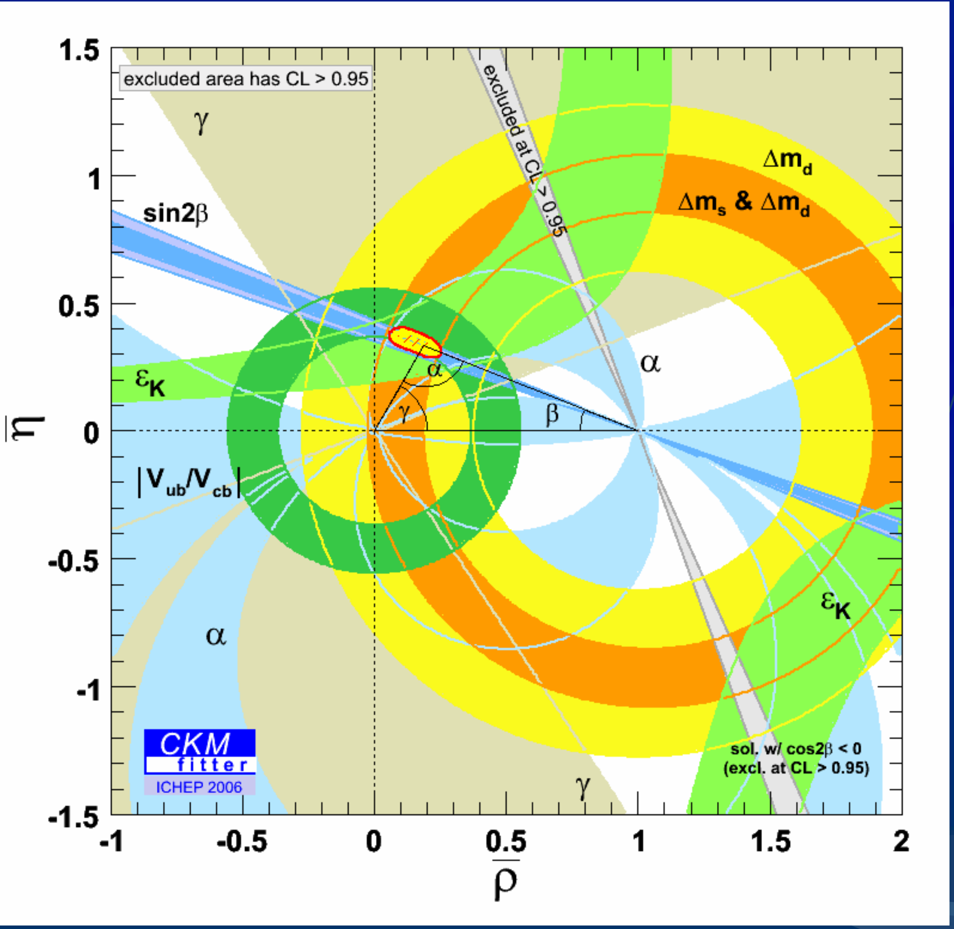


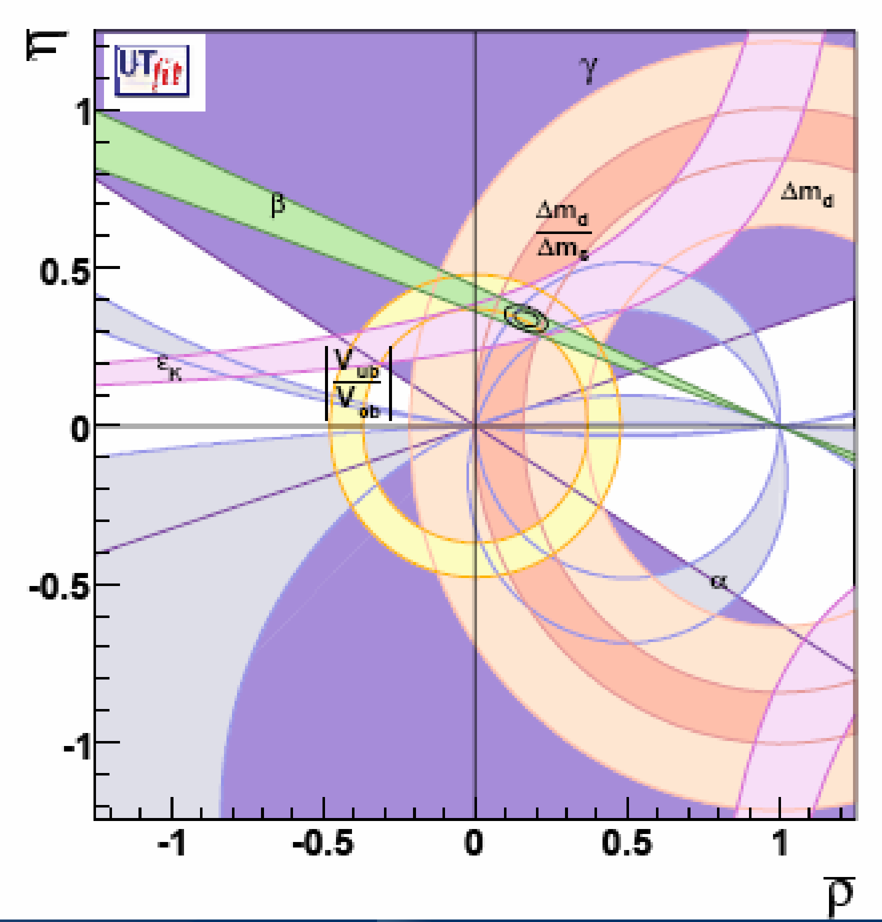
Backup slides

Tale of two fitters

CKMfitter (frequentist)

UTFit (Bayesian)





Theory calculations

- Bosch, Lange, Neubert, Paz (BLNP)
  - Decompose into Hard, Jet and Shape functions using HQE and SCET: $H \times J \times S$
  - Same formalism used to extract m_b and μ_π^2 from $b \to s\gamma$
  - Predictions over full phase space, reasonable error analysis
  - Critique: 3 scales between Λ_{QCD} and m_b
- Andersen and Gardi: Dressed gluon exponentiation (DGE)
  - Only m_b and α_S as input parameters
  - Gives good description of $b \to s\gamma$ spectrum
  - Agrees fairly well with BLNP on $b \to u\ell\nu$ rates
  - Critique: some (but not all) consider it a model;

Global fit: Input measurements

- Moments used in fit, from $B \to X_c \ell \nu$ and $b \to s\gamma$

Buchmüller and Flächer, Phys.Rev. D73 (2006) 073008

\ Moment Experiment	Electron energy	Hadronic mass	Photon energy
Delphi	**3**	**3**	
CLEO	need full covar	**4**	**1**
CDF		**2**	
Belle	need full covar	need full covar	**4**
BaBar	**14**	**13**	**3**

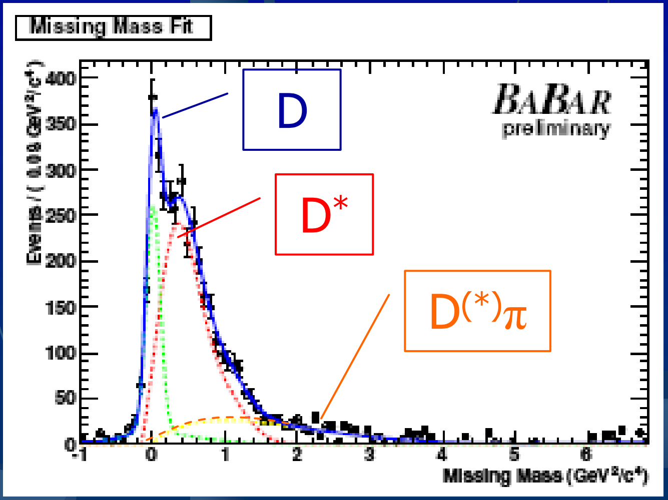
$B \to X_c \ell \nu$ using tagged samples

- Reconstruct $D^{(*)}X\ell^-\nu$ across from a fully reconstructed B^+ or B^0 meson; M_{miss}^2 provides new kinematic handle
- Belle reported last year BFs for $B \to D^{(*)}\pi\ell\nu$: Phys.Rev.D72:051109,2005

	Belle BF (in %)
$D^+\pi^-\ell^-\bar{\nu}_\ell$	$0.54 \pm 0.07 \pm 0.07 \pm 0.06$
$D^{*+}\pi^-\ell^-\bar{\nu}_\ell$	$0.67 \pm 0.11 \pm 0.09 \pm 0.03$
$D^0\pi^+\ell^-\bar{\nu}_\ell$	$0.33 \pm 0.06 \pm 0.06 \pm 0.03$
$D^{*0}\pi^+\ell^-\bar{\nu}_\ell$	$0.65 \pm 0.12 \pm 0.08 \pm 0.05$

Also report $BF(B^- \to D^{*0}\ell^-\nu) = 6.06 \pm 0.25_{stat}\%$;
and $BF(\underline{B}^0 \to D^{*+}\ell^-\nu) = 4.70 \pm 0.24_{stat}\%$.

- New BaBar preliminary result:
  $BF(B^- \to D^{*0}\ell^-\nu) = 6.8 \pm 0.4\%$
  $BF(B^- \to D^0\ell^-\nu) = 2.3 \pm 0.3\%$
  $BF(B^- \to D^{**0}\ell^-\nu) = 1.9 \pm 0.3\%$
  (includes $D^{(*)}\pi\ell\nu$; translated from relative fractions into BFs by this speaker assuming these modes saturate $b \to c\ell\nu$)

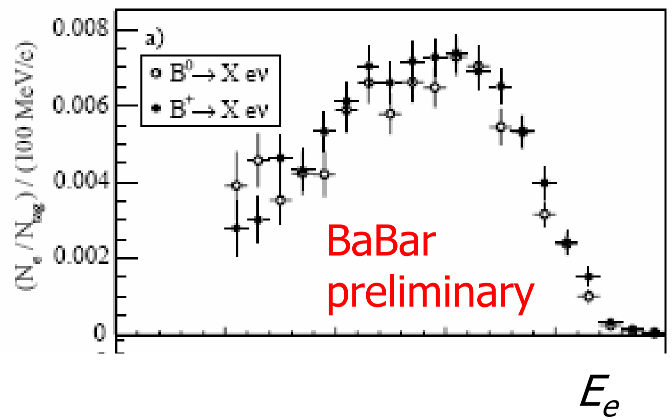


- New D0 result (preliminary)
  $BF(B_s \to D_{s1}(2536)\ell\nu) = 0.86 \pm 0.16 \pm 0.16$

The BF($B \rightarrow D^* \ell\nu$) puzzle

- The largest B BF is $B \rightarrow D^* \ell\nu$ (~6%), yet $B \rightarrow K^*\gamma$ (~4×10^{-5}) is known as well, and perhaps better…
- (HFAG winter) average: BF($\underline{B}^0 \rightarrow D^{*+}\ell^-\nu$) = 5.35 ± 0.20%; CL=3.8%
- Consider R_{D*} = BF($B^- \rightarrow D^{*0}\ell^-\nu$) / BF($\underline{B}^0 \rightarrow D^{*+}\ell^-\nu$); we expect $R_{D*} = \tau_+ / \tau_0 = 1.071 \pm 0.009$
- Naively combining Belle and BaBar results: $R_{D*} = 1.32 \pm 0.07$ (20% and 3.5σ from isospin!)

Total BF($B \rightarrow X\ell\nu$) consistent with isospin



BF($B^+ \rightarrow Xe\nu$) / BF($B^0 \rightarrow Xe\nu$) = 1.084 ± 0.041 ± 0.025

Importance of r_B

- The uncertainty on γ (φ_3) depends strongly on the value of r_B, which is currently not well known
- Predictions for how σ_γ will evolve with luminosity have significant uncertainty