Measurements of CKM Elements and Unitarity Triangle

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Aim:

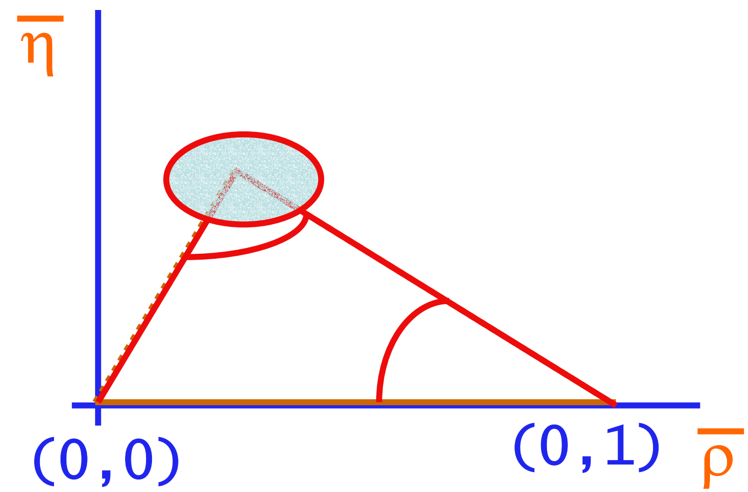
constraints on CKM matrix

consistency between data/SM

$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\bar\rho - i\bar\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\bar\rho - i\bar\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

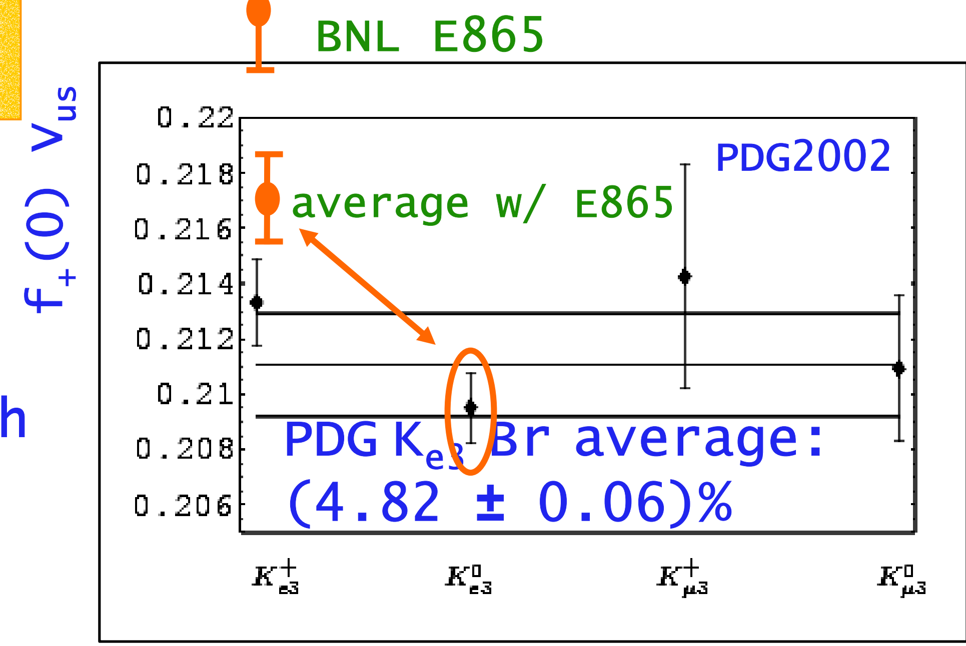
- Cabbibo angle
- tree level B decays
- oscillations
- angles
- overall constraints

detailed insight from talks by K. Abe and Y. Pan



$|V_{us}|$

from $K^{+(0)} \to \pi^{0(-)}\, l^+\, \nu_e$



$|V_{us}|$ from E865

designed for $K^+ \to \pi^+\mu^+e^-$ search

1 week dedicated K_{e3} run 1998

$Br(K^+ \to \pi^0\, e^+\, \nu_e) =$

$(5.17 \pm 0.02 \pm 0.09 \pm 0.04)\%$

$|V_{us}| = 0.2272 \pm 0.0028$

± 0.0020 theoretical uncertainty ($f_+(0)$);

(E865, hep-ex/0305042)

Unitarity…?:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

$|V_{ud}|_{direct} = 0.9740 \pm 0.0005$ (SFT)

$|V_{us}|_{direct} = 0.2201 \pm 0.0024$ (Ke3, w/o E865)

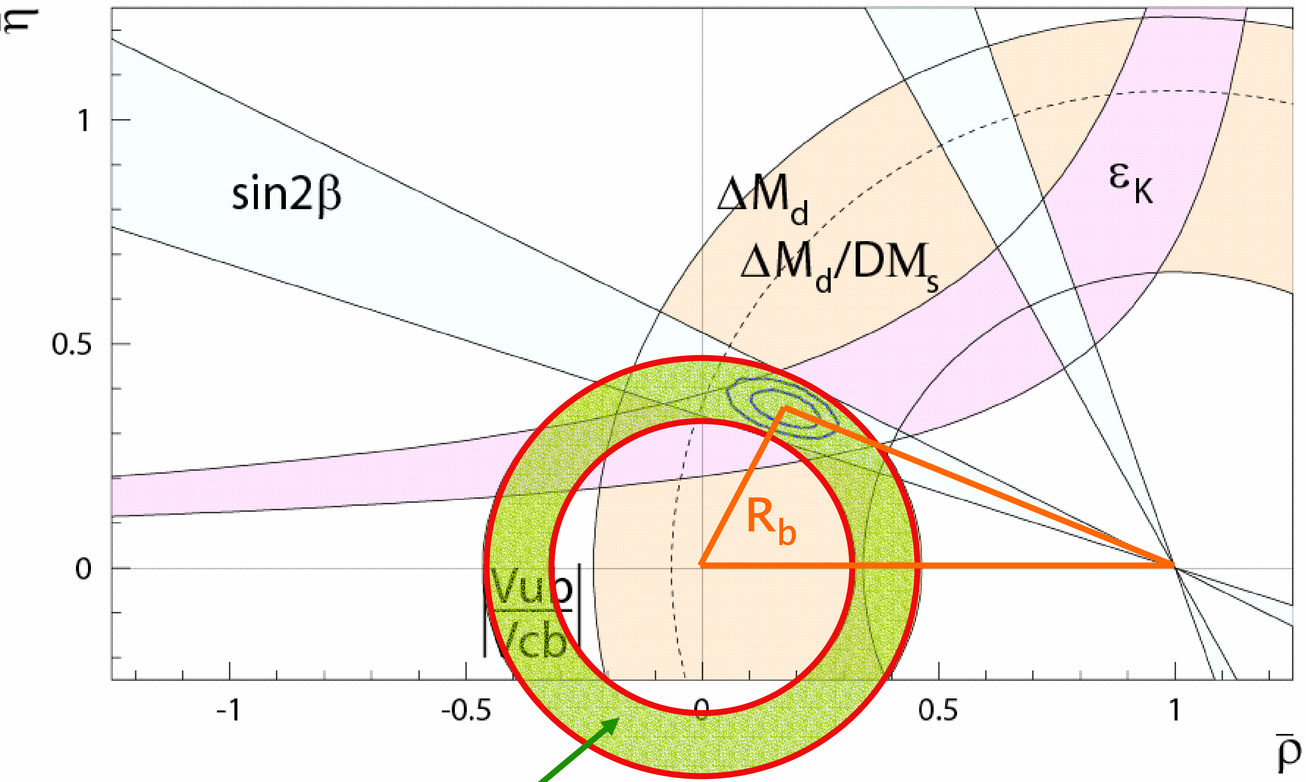
$|V_{us}|_{unitarity} = \sqrt{(1 - |V_{ud}|^2_{direct})}$
$= 0.2265 \pm 0.0022$

~2 σ discrepancy

solved by E865?

$|V_{cb}|, |V_{ub}|$

From tree-level B decays

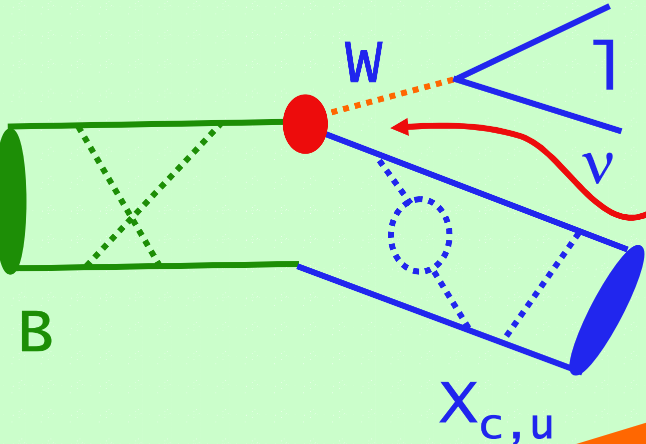


$\left|\frac{V_{ub}}{V_{cb}}\right|$

Apex of unitarity triangle must lie within the band (independent of new physics); constrains the side R_b

$|V_{cb}|, |V_{ub}|$

From tree-level (s.l.) B decays



- V_{cb}
- V_{ub}

- exclusive

mainly $B \to D^* l\nu$ (higher stat., lower th. uncertainty);
also $B \to D l\nu$ as check

- inclusive

total s.l. width + moments of differential distributions

- exclusive

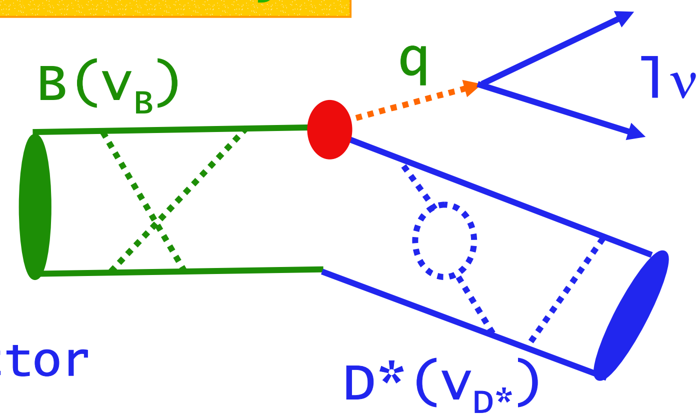
$B \to \pi,\rho,\omega,\eta\ l\nu$;
HQS not helpful, high th. uncertainty

- inclusive

total s.l. $b \to u l\nu$ width;
limited phase space, larger th. uncertainty than $b \to c l\nu$

$|V_{cb}|$ from exclusive decays

Measurement of w distribution



$$w = \frac{M_B^2 + M_{D*}^2 - q^2}{2M_B M_{D*}} = v_B v_{D*}$$

known kinematic factor

$$\frac{d\Gamma(B \to D^* \ell \bar{\nu})}{dw} \propto |V_{cb}|^2 \mathcal{K}(w, m_B, m_{D*}) \mathcal{F}^2(w)$$

form factor

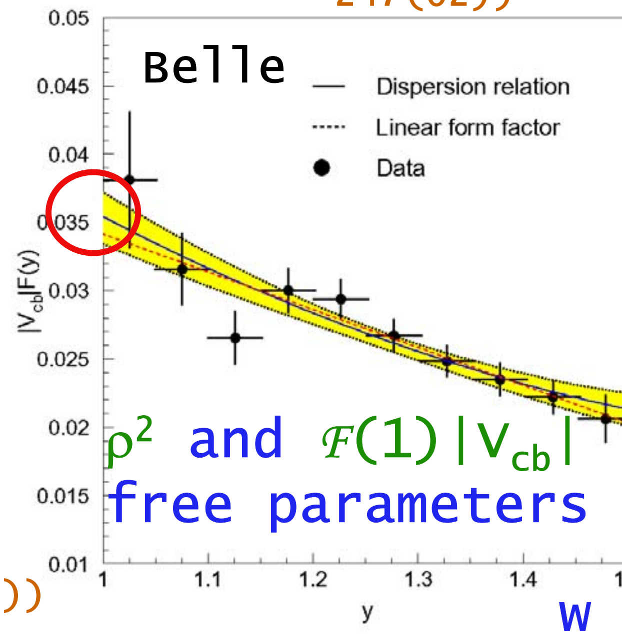
(Belle, PLB526, 247(02))

In the heavy quark limit:

$\mathcal{F}(w) = \xi(w)$ $\xi(1) = 1$

Extrapolation of

$d\Gamma/dw$ to $w=1 \rightarrow \mathcal{F}(1)|V_{cb}|$



ρ^2 and $\mathcal{F}(1)|V_{cb}|$ free parameters

w

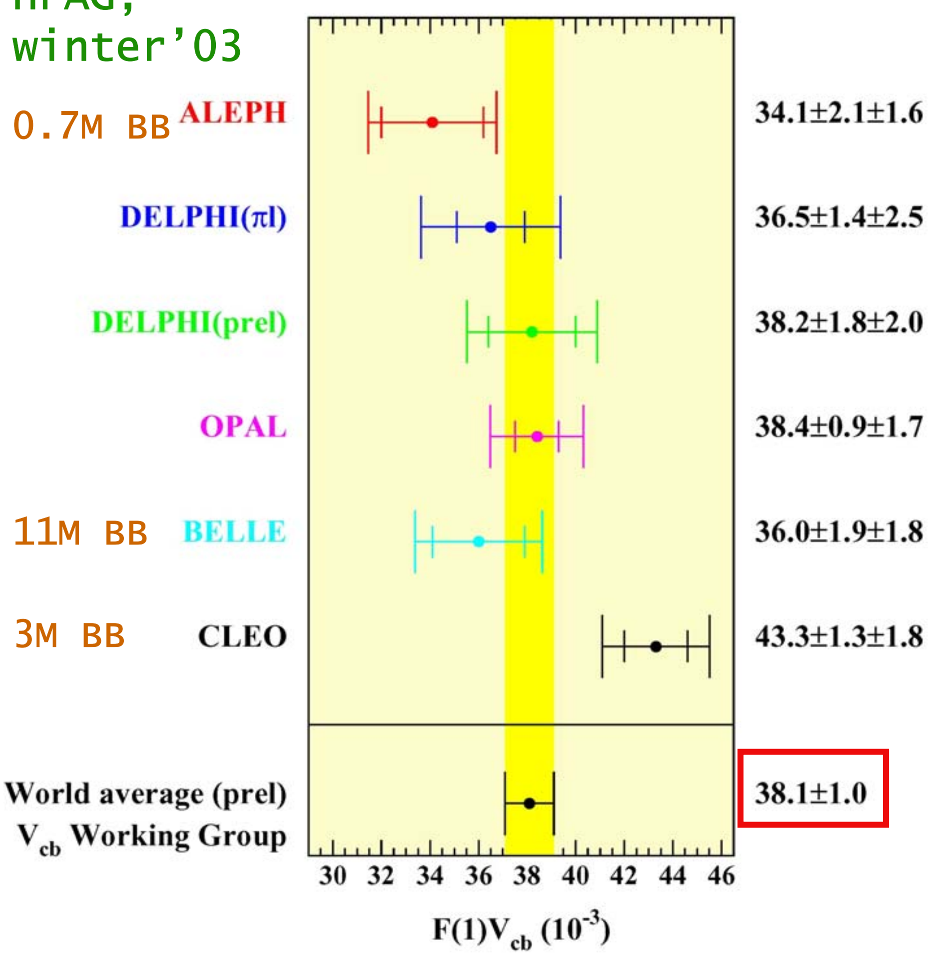
$$\mathcal{F}(w) = \mathcal{F}(1)\mathcal{K}(w)\left(1 - 8\rho^2 z + \ldots + O(z^4)\right)$$

$$z = \frac{\sqrt{w+1} - \sqrt{2}}{\sqrt{w+1} + \sqrt{2}}$$

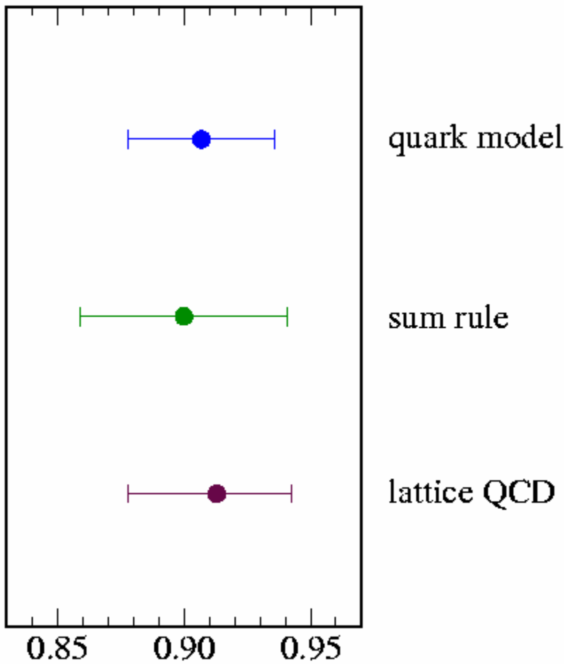
(I.Caprini et al., Nucl.Phys.B530,153(98))

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

HFAG, winter'03



meas. error dominated by systematics:
Z^0: modeling of D** bckg
$\Upsilon(4s)$: $\varepsilon(\pi_{slow})$



$\mathcal{F}(1) = 0.91 \pm 0.04$

$$|V_{cb}| = (41.9 \pm 1.1 \pm 1.8) \times 10^{-3}$$

exp. $\mathcal{F}(1)$

$|V_{cb}|$ from inclusive decays

Measurement of semileptonic width Γ_{sl}

~1% accuracy on $|V_{cb}|$ $\quad$ $Br(b \to cl\nu)/\tau_b = K_{th} |V_{cb}|^2$ $\quad$ ~5% uncertainty on $|V_{cb}|$

Operator Product Expansion:

two parameters to $O(1/m_b^2)$:

λ_1 (kin. energy of b);

λ_2 (hyperfine int. energy);

$+ \; m_b = m_B - \bar{\Lambda}$

use to constrain/check theory

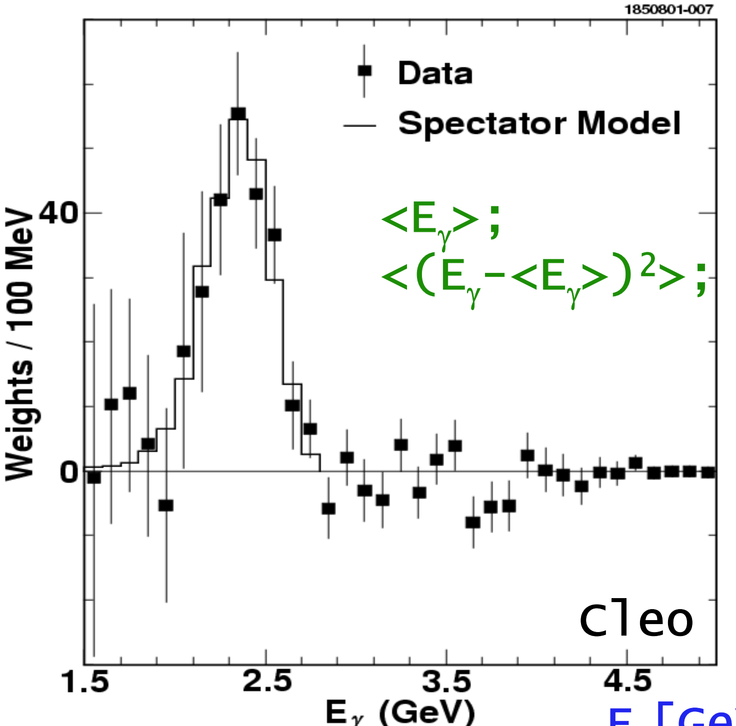
corrections described by same parameters also for different moments of differential distributions

$$M_n(X) = \frac{1}{\Gamma} \int X^n \frac{d\Gamma}{dX} dX$$

$X = E_l, \; M_h, \; E_\gamma$

$|V_{cb}|$ from inclusive decays

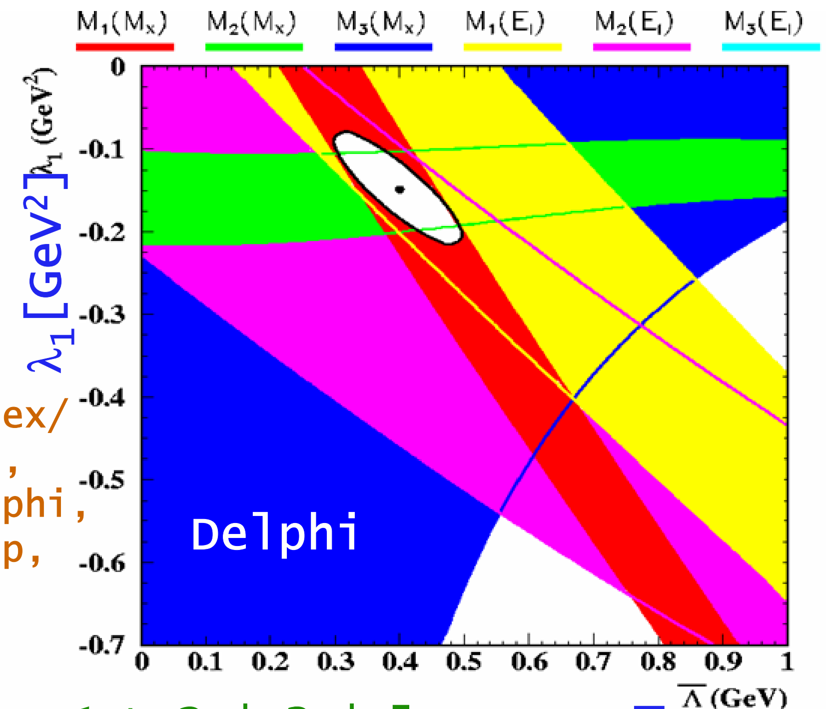
several moments measured:



E_γ[GeV]

E_γ from $b \to s\gamma$;

(Delphi,hep-ex/ 0210046(02), M.Calvi,Delphi, CKM Workshop, Durham'03)



$\bar{\Lambda}$[GeV]

1st,2nd,3rd lepton energy and hadronic mass moments;

(Cleo,PRL87, 251807(01); Cleo,PRL87, 251808,(01); Cleo,PRD67, 072001(03))

Cleo also moments of
- hadronic mass spectrum
- lepton energy

from $B \to Xl\nu$;

BaBar: moments of hadronic mass; p* dependence stronger than expected, analysis ongoing;

$|V_{cb}|$ from inclusive decays

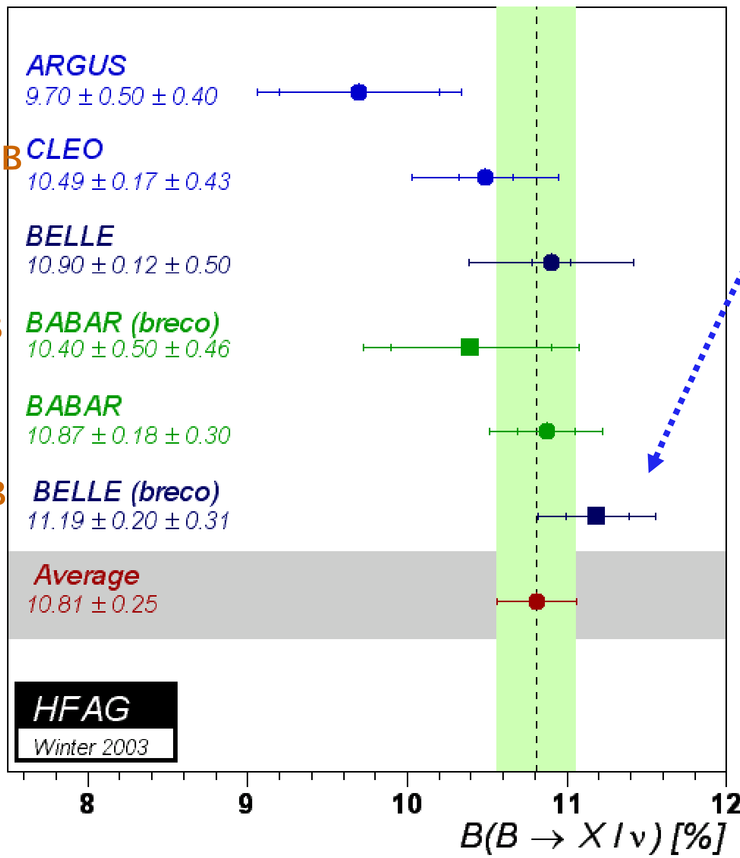
HFAG Winter'03 average

LEP:
$Br(B \to Xl\nu)=(10.65\pm0.23)\%$
(advantage: full lepton spectrum)

2.2M BB

22M BB

82M BB



using world average
$\Gamma_{sl} = (0.434\pm0.008)10^{-10}$ MeV
(some measurements not yet included)

and combining different measured moments, also 3rd (sensitive to $O(1/m_b^3)$, multiparameter fits):

(C.W.Bauer et al.,PRD67,054012(03); M.Battaglia et al.,PLB556,41(03))

$|V_{cb}| =$
$(41.4 \pm 0.7 \pm 0.6)\text{x}10^{-3}$
exp. th.

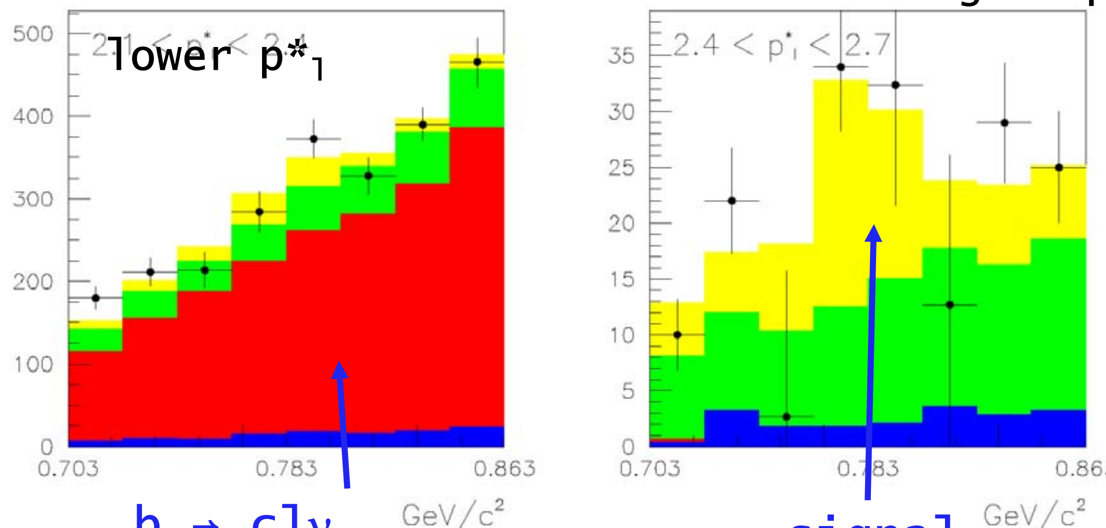
exp.: Γ_{sl}, $\bar{\Lambda}$, $\lambda_1, \rho_1, \rho_2$

th.: α_s, $O(1/m_b^4)$

$|V_{ub}|$ from exclusive decays

Measurements of
$Br(B \to X_u l n)$;
several measurements
exist:
BaBar, Belle, Cleo
covering
$B \to \pi^{\pm}, \pi^0, \rho^{\pm}, \rho^0, \omega, \eta\ l\nu$

$B \to \omega l \nu$



(C.Schwanda, Belle, CKM Workshop, Durham'03)

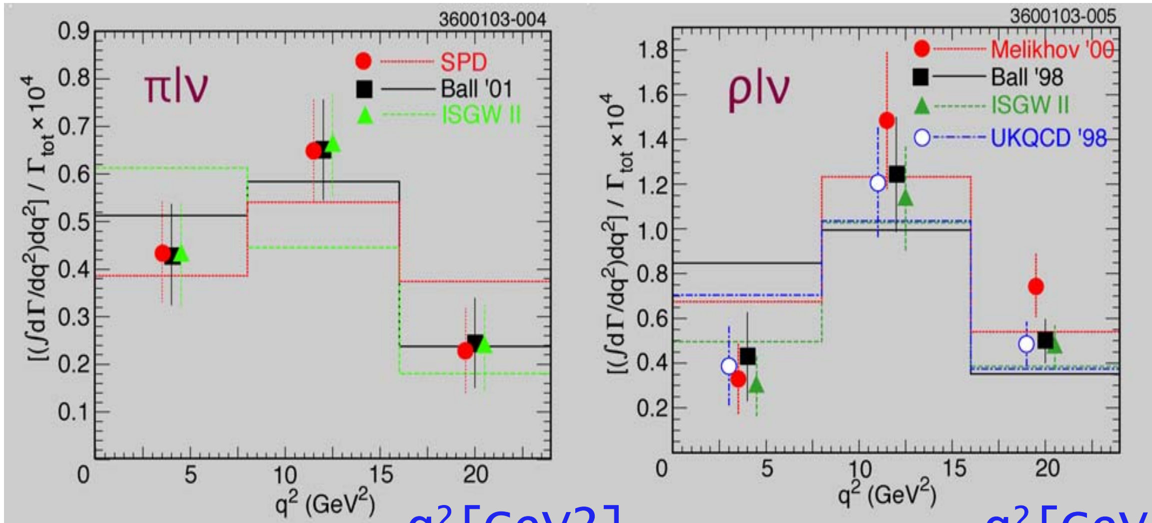
- similar as $b \to c l \nu$, but in limited interval of q^2 (Cleo, $\pi l \nu$, $\rho l \nu$) p^*_l, E_l (Belle, $\omega l \nu$), (BaBar, $\rho l \nu$)
- fit to obtain yield (use isospin relations to connect $\pi(\rho)^{\pm} l \nu$ and $\pi(\rho)^0 l \nu$)
- extrapolate to full range (q^2, E_l) using different models;

↓

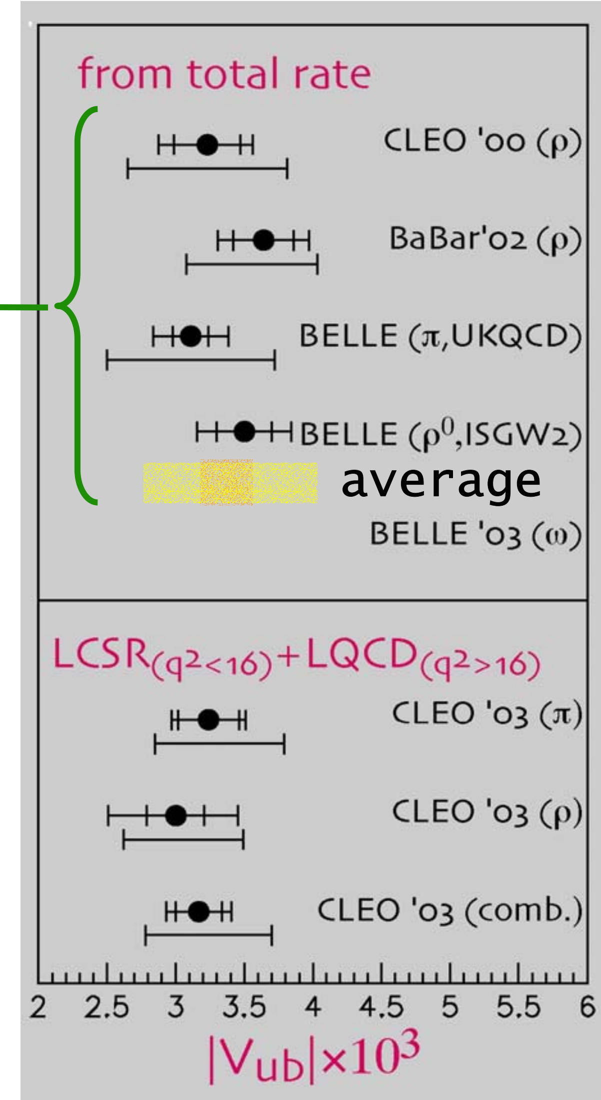
source of theoretical uncertainty

$|V_{ub}|$ from exclusive decays

(L.Gibbons,Cleo, CKM Workshop,Durham'03)



q^2[GeV2] q^2[GeV2]



Cleo: $B \to \pi l \nu$,
$B \to \rho l \nu$

2D $M(X_u l\nu)$, ΔE fit separately in three q^2 bins

lower syst. from $\varepsilon(q^2)$; low probability ISGW2;

evaluation of th. uncertainty;
difficult to combine;

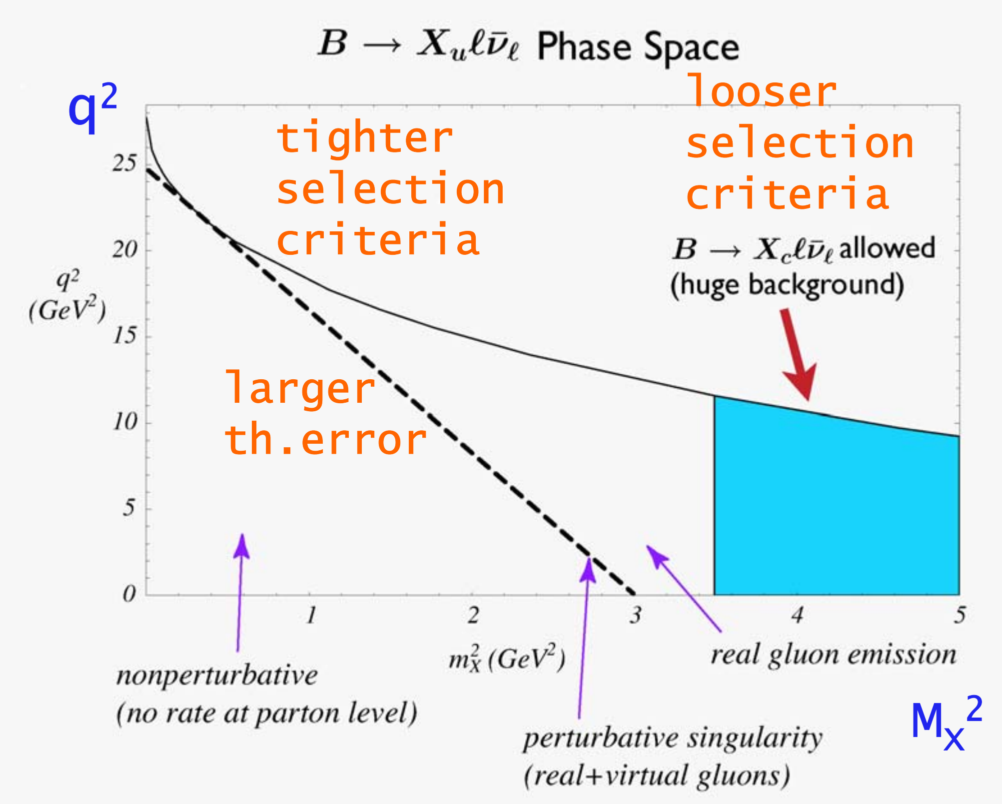
$$|V_{ub}| = (3.42 \pm 0.22 \pm 0.55) \times 10^{-3}$$

exp. th.

$|V_{ub}|$ from inclusive decays

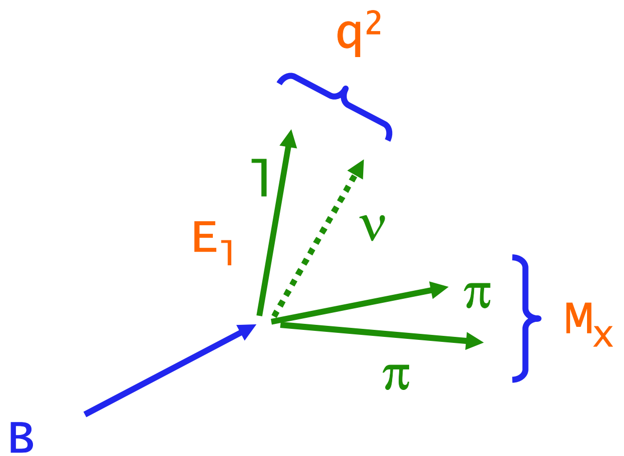
(plots from M.Luke, CKM Workshop, Durham'03)

Semileptonic width $b \to ul\nu$ sensitive to V_{ub} in analog way as $b \to cl\nu$ sensitive to V_{cb};



Variables separating $b \to ul\nu$ from $b \to cl\nu$:

- lepton energy E_l;
- hadronic inv. mass M_X;
- leptonic inv. mass q^2;



Number of measurements using different individual variable or combination of those.

$|V_{ub}|$ from inclusive decays

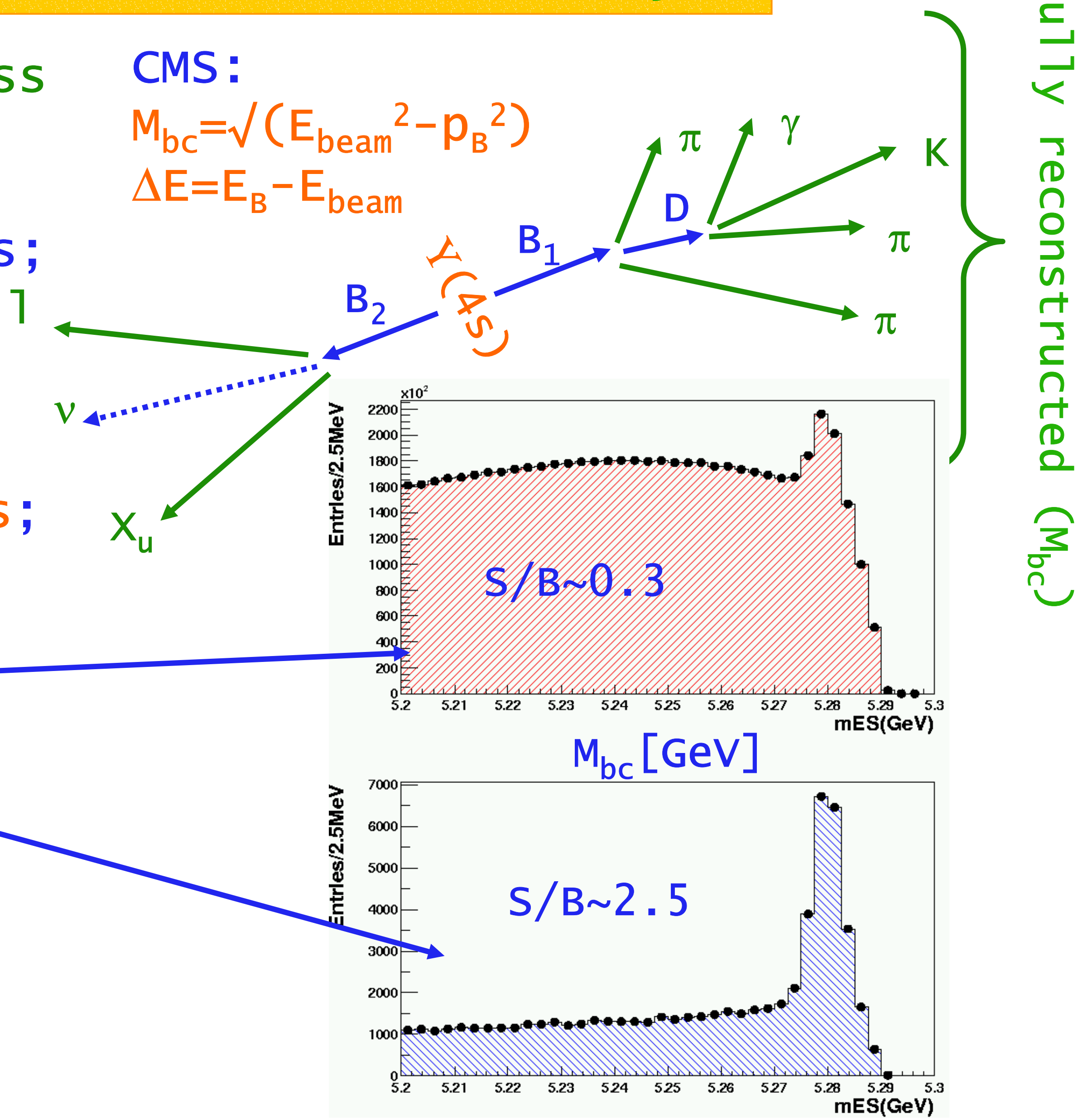
Hadronic invariant mass

- at $\Upsilon(4s)$ need to separate decay products of two B's;
- large sample of B's → can use fully reconstructed events;

CMS:

$M_{bc}=\sqrt{(E_{beam}^2-p_B^2)}$

$\Delta E=E_B-E_{beam}$



BaBar:

$B \to D^{(*)}+n\pi$

ε~0.4%

selecting p^*_l>1 GeV on recoiling side;

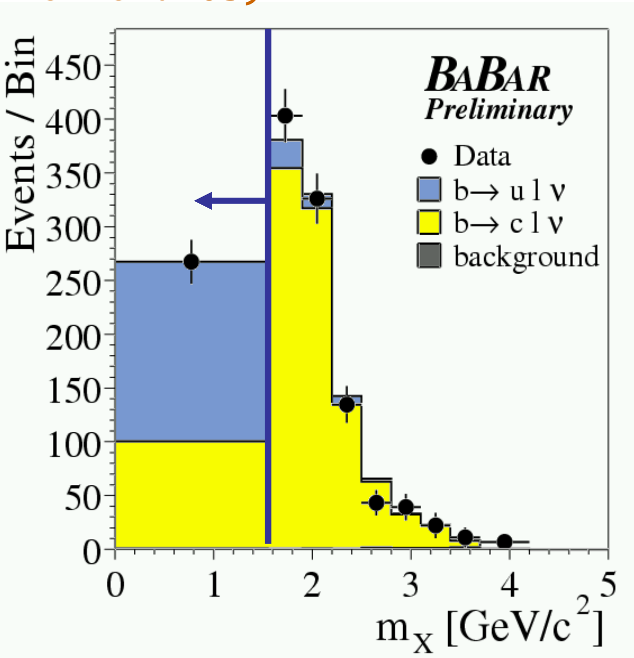
(D.del Re, BaBar, Moriond'03)

$|V_{ub}|$ from inclusive decays

calculate M_X on recoiling side;

fit with $b \to u l \nu$, $b \to c l \nu$, bckg.; extract $Br(B \to X_u l \nu)/Br(B \to X l \nu)$

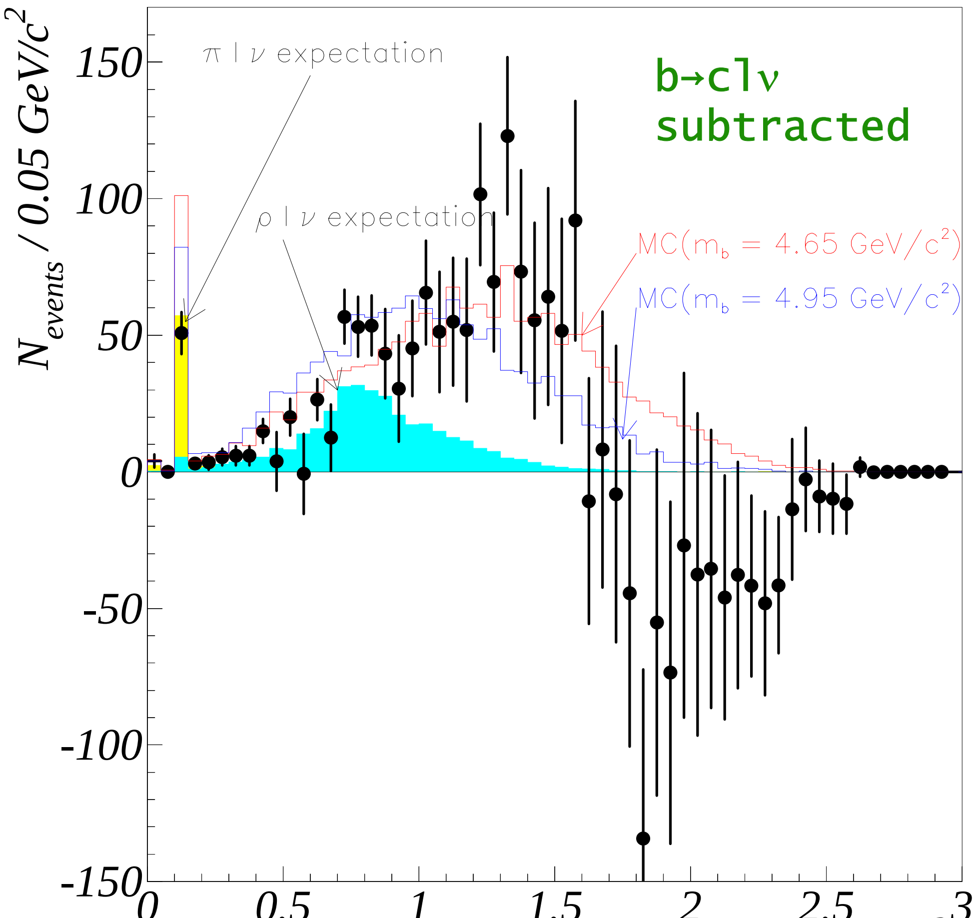
(D.del Re, BaBar, Moriond'03)



Belle: simulated annealing technique; minimize

$$W = \frac{\mathcal{L}(random)}{\mathcal{L}(random) + \mathcal{L}(correct)}$$

exchange particle signal ↔ tagging side



(A.Sugiyama,Belle,Moriond'03)

$|V_{ub}|$ from inclusive decays

Inclusive V_{ub} summary (HFAG winter'03):

no average for B factories;

all measurements suffer from th. uncertainty;

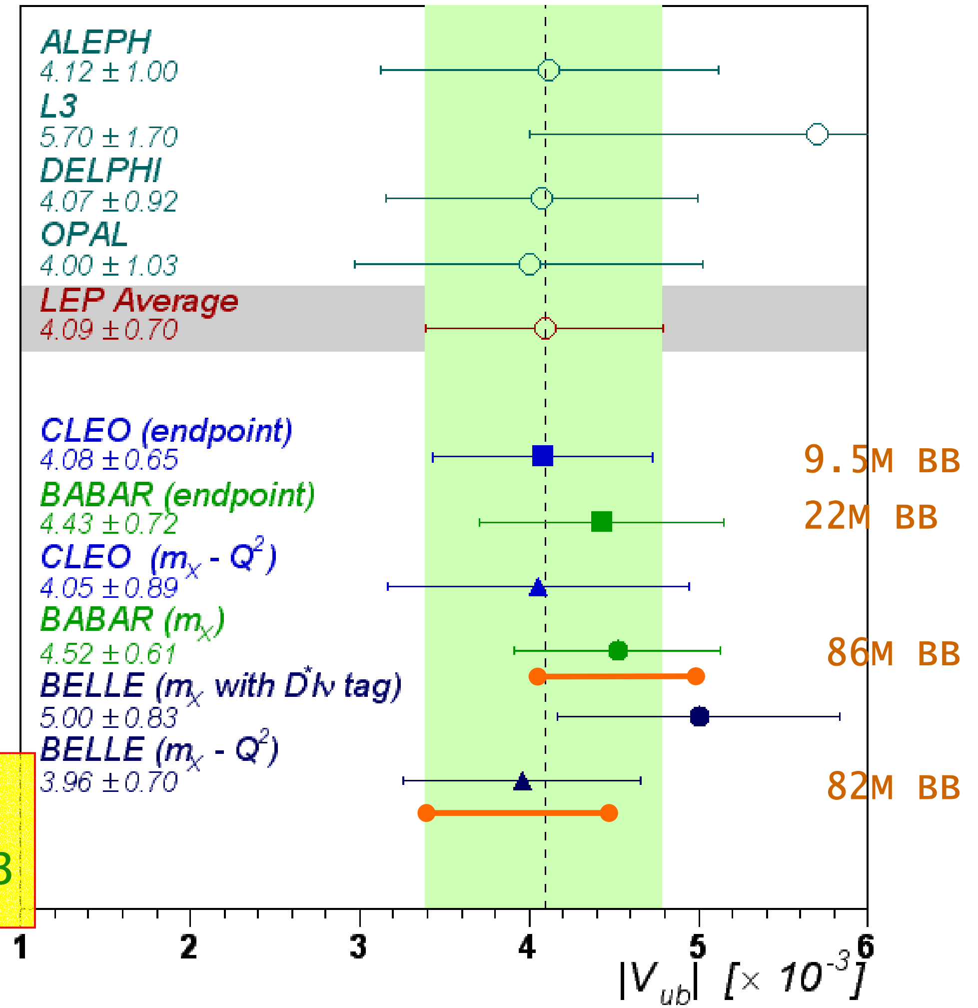
lepton endpoint results:

error from sh.f.,th.,sγ completely correlated

exp. syst. uncorrelated

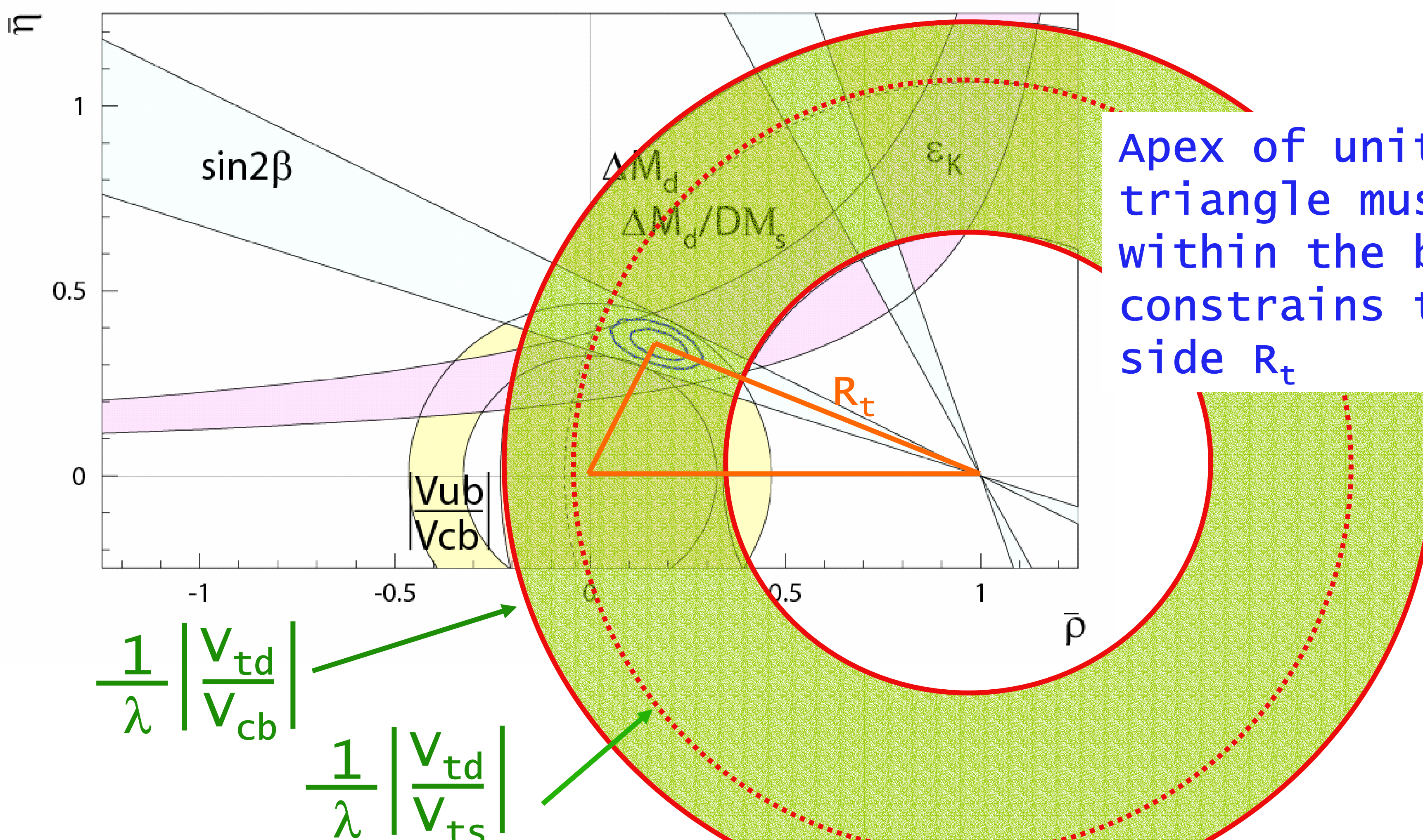
$|V_{ub}| = (4.28 \pm 0.17 \pm 0.62)\times 10^{-3}$

exp. th.



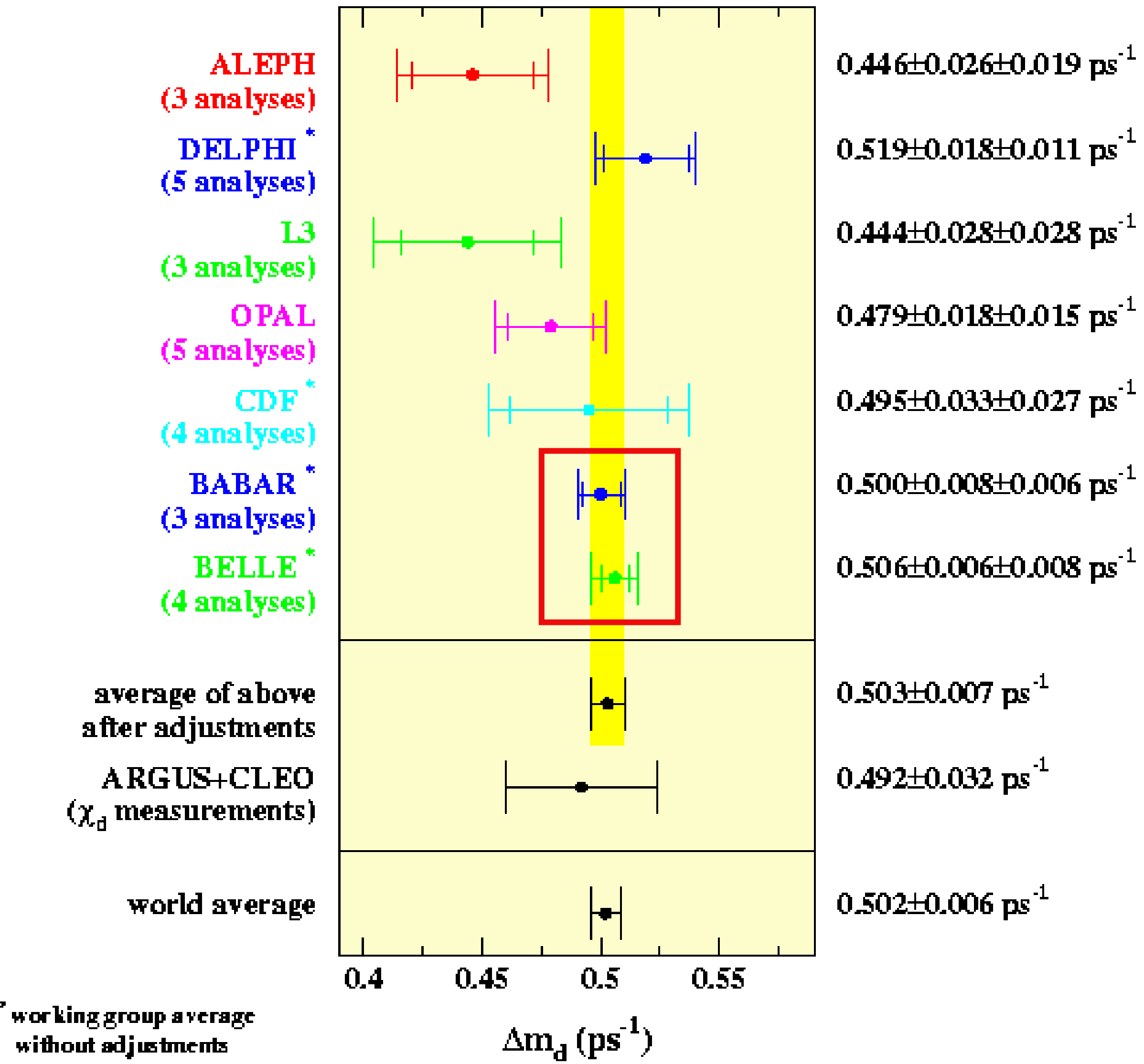
$|V_{td}|, |V_{ts}|$

From $B_{d,s}$ oscillations



Apex of unitarity triangle must lie within the band; constrains the side R_t

B_d oscillations



HFAG,winter'03

1.2% relative error on Δm_d

to extract $|V_{td}|$

$F_{Bd}\sqrt{B_{Bd}}$ = 220±35MeV (LQCD)

B_s oscillations

Amplitude method:

$$P_{u,m} = \frac{1}{2}\Gamma_s e^{-\Gamma_s t}\left[1 \pm A\cos(\Delta m_s t)\right]$$

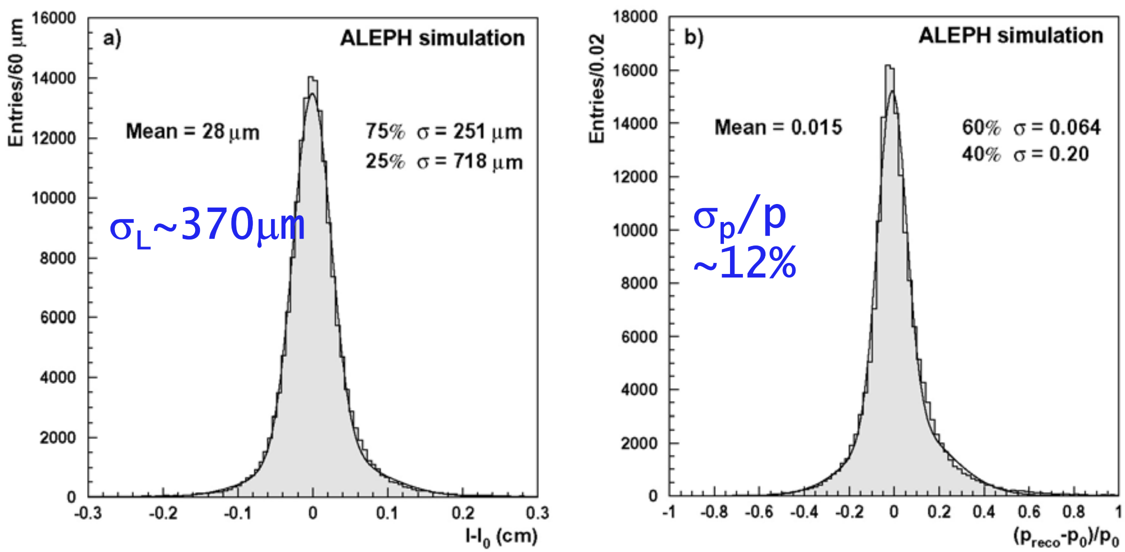
instead of Δm_s free parameter, fit A at fixed value of $\Delta m_s \rightarrow A(\Delta m_s)$;
no oscillations: A=0;
oscillations at given Δm_s: A=1
Δm_s excluded @95% C.L. where $A(\Delta m_s)+1.645\sigma_A < 1$

(Aleph,CERN-EP-2002-16)

Aleph:
combination of 3 methods;
- exclusive ($B_s \rightarrow D_s^{(*)}\pi(a_1,\rho)$),
- semi-inclusive (rec. D_s and lepton),
- inclusive (semileptonic);

increasing stat.

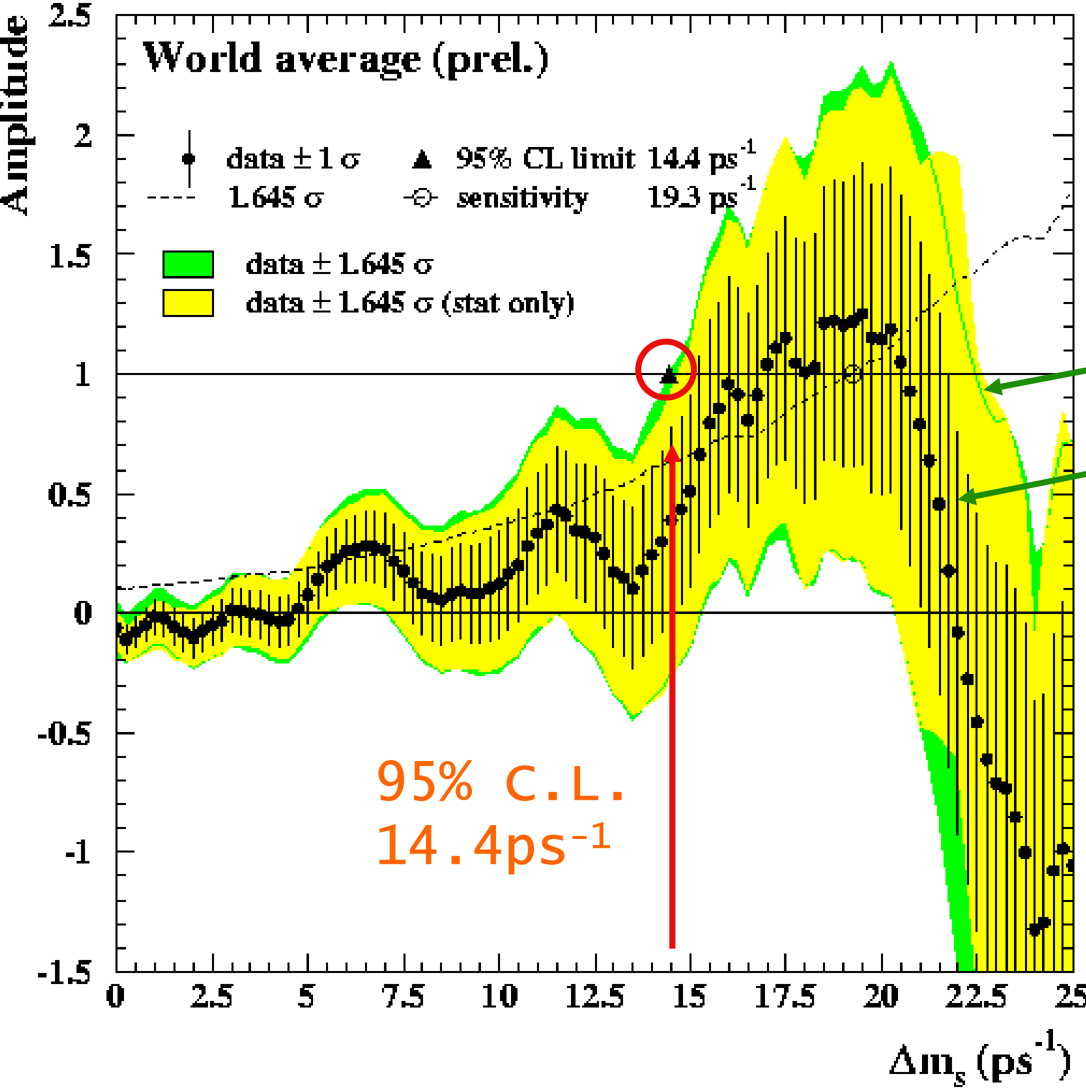
increasing p and L resolution



inclusively rec. D vtx.;
p_B using p_{miss} and p_D;

$\sigma_A \sim \exp(\Delta m_s^2 \sigma_t^2/2)$!

B_s oscillations



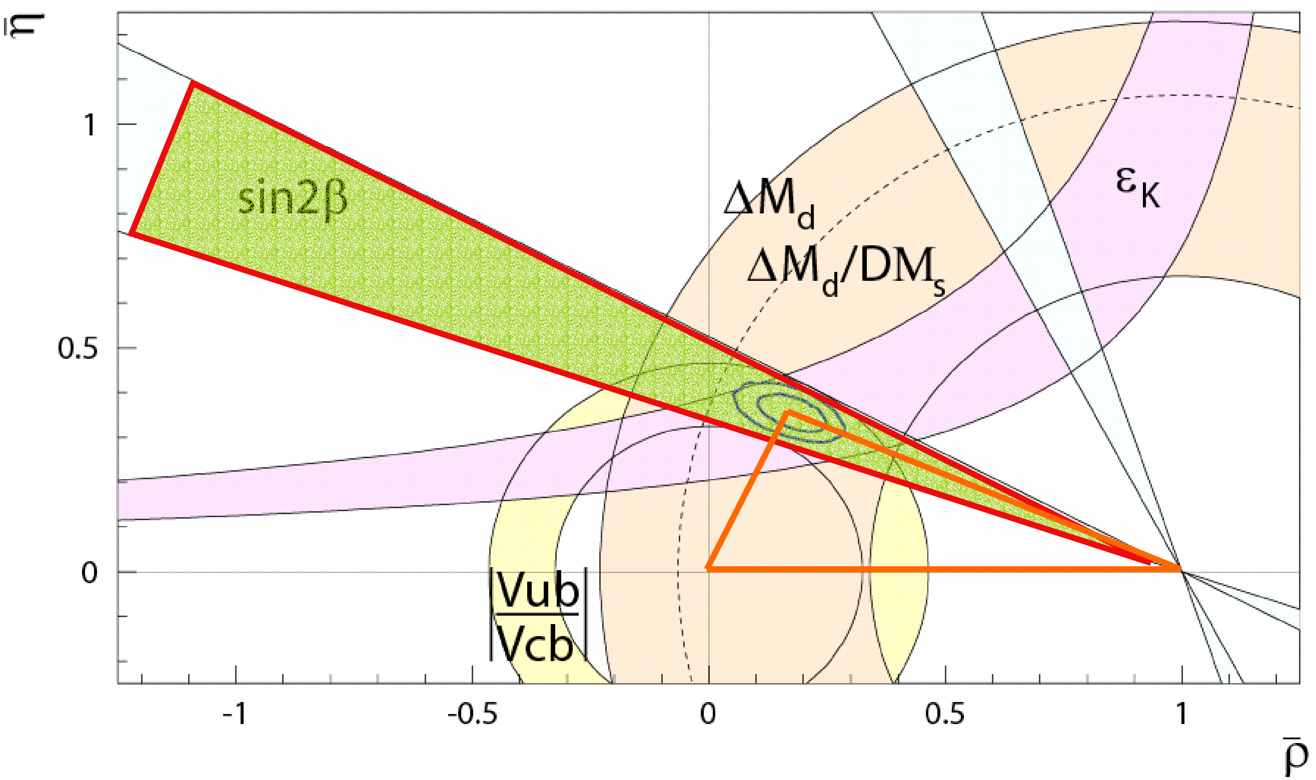
HFAG, winter'03:
average of amplitude measurements;

data ± 1.645σ

data ± 1σ

next test of SM in CKM fits;
Tevatron domain until LHC;

Angle $\sin 2\phi_1(\beta)$



…is one of the angles of UT… ☺

measured in

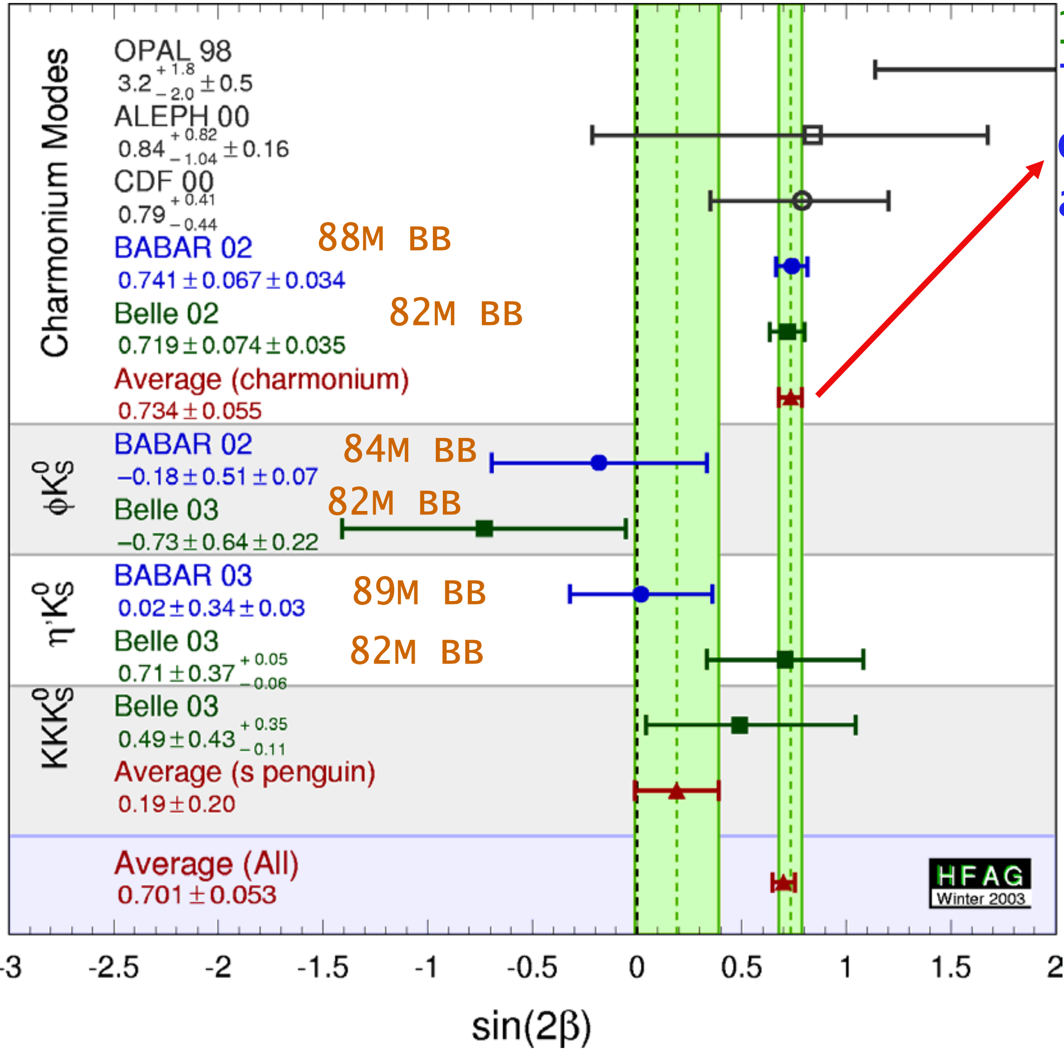
$b \to c\bar{c}s$
$B \to J/\Psi\, K_s$

$b \to c\bar{c}d$
$B \to D^+D^-$

$b \to s\bar{s}s$
$B \to \phi\, K_s$

HFAG, winter'03

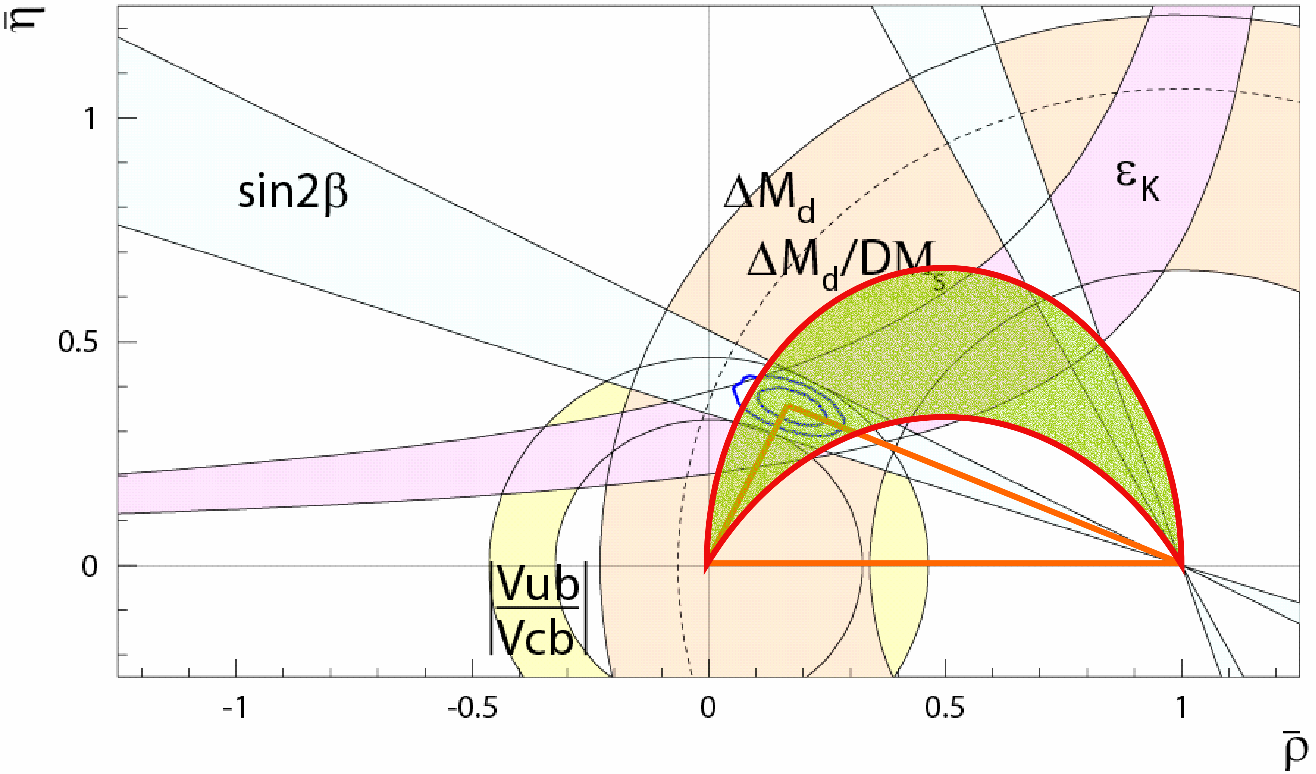
$\sin 2\phi_1(\beta)$



1±0.07 precision measurement, limited by stat. (by factor of 2; ~50% more stat. already waiting)

average: -0.38±0.41;
$b \to s\bar{s}s$, penguin only w/ different phase, one suppressed by $O(\lambda^2)$;
th. clean, with increased stat. might reveal new phenomena

Angle $\sin 2\phi_2 (\alpha)$



…is another angle of UT…

…but more difficult to access than ϕ_1!

measured in

$b \rightarrow u\bar{u}d$

$B \rightarrow \pi^+\pi^-$

significant

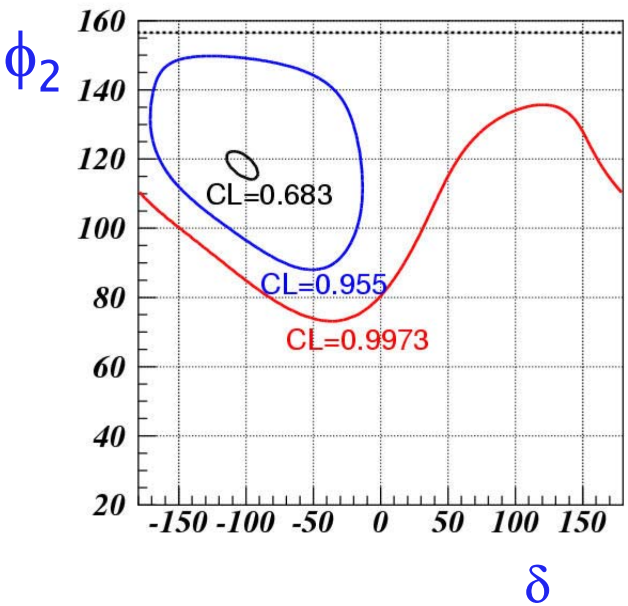
sin2ϕ_2(α) from B → ππ

sin2ϕ_2 "summary":

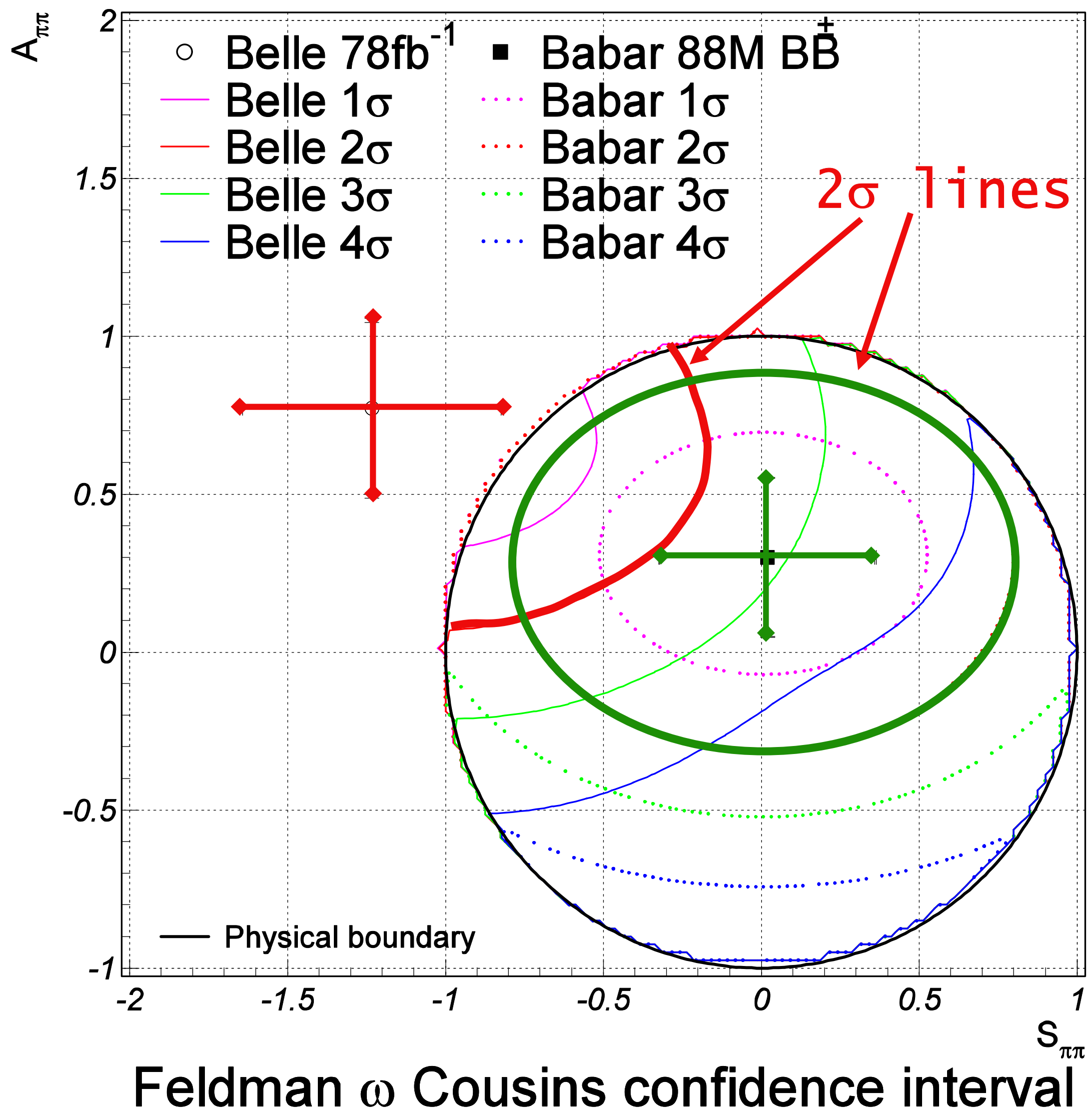
(H.Sagawa,FPCP'03)

Belle B → ππ:

(|P/T|=0.3, sin2ϕ_1)



$78^o \leq \phi_2 \leq 152^o$ @95%C.L.
(independent of δ)



CKM fit

Standard fit:
use measured observables and th. parameters
to constrain the region in $(\bar{\rho},\bar{\eta})$ plane (CKM Fitter group, http://ckmfitter/in2p3.fr)

Inputs(some):

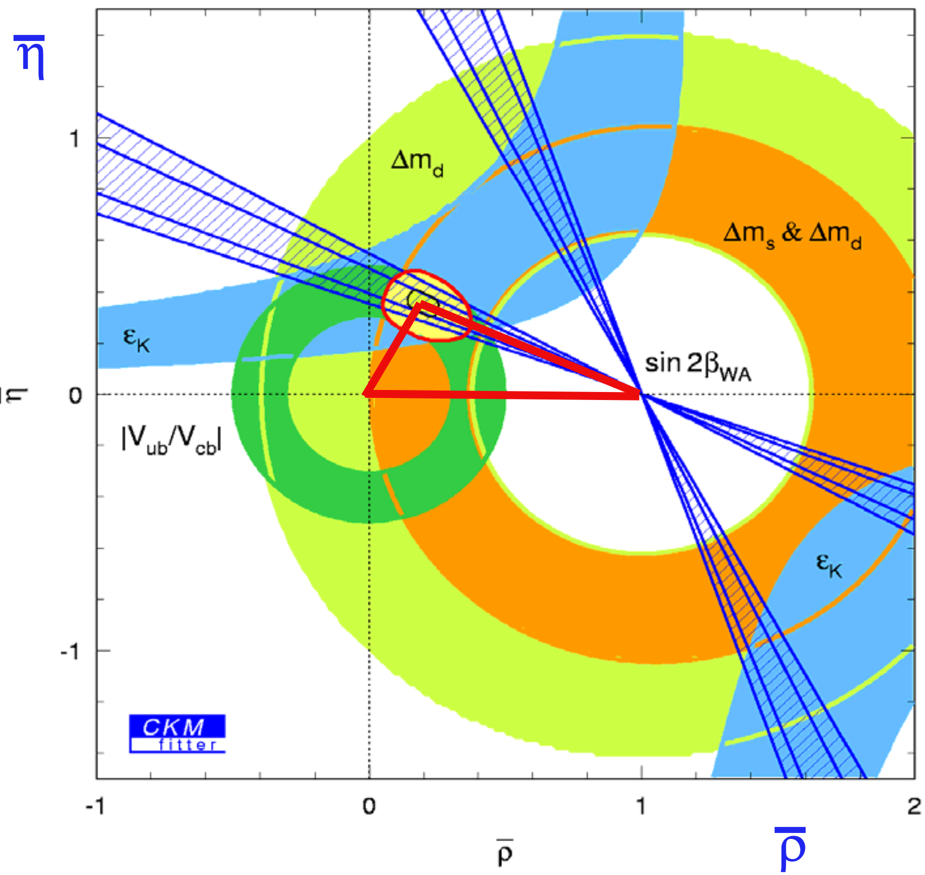
Experimental	Theoretical
$\lvert V_{ud}\rvert$, $\lvert V_{us}\rvert$, $\lvert V_{ub}\rvert$, $\lvert V_{cb}\rvert$	η_B, $f_{Bd}\sqrt{B_{Bd}}$, ξ, B_K,…
ε_K, Δm_d, Δm_s, $\sin 2\phi_1$, m_t,…	

Rfit approach:
theoretical uncertainties ↔ constant likelihood
Minimize $\mathcal{L}(y_{\mathrm{mod}}) = \mathcal{L}_{\mathrm{exp}}(x_{\mathrm{exp}} - x_{theo}(y_{\mathrm{mod}}))\cdot\mathcal{L}_{theo}(y_{\mathrm{mod}})$
and compute CL.

⇓ nice plots

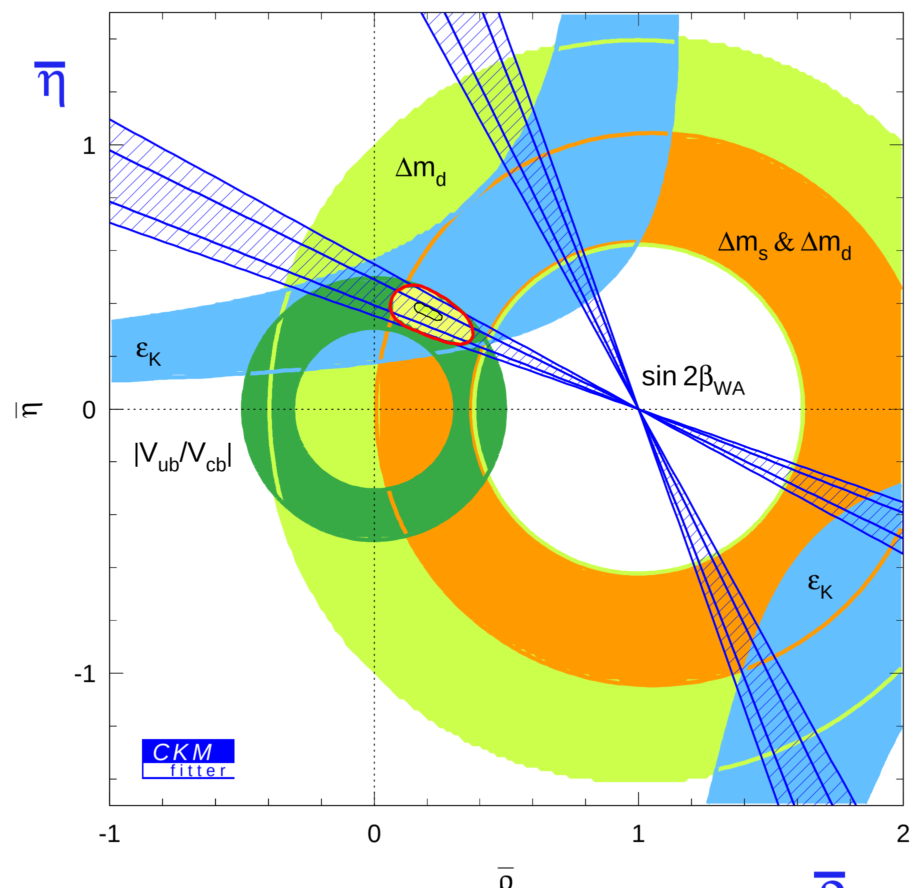
UT constraints

(CKM Fitter group, http://ckmfitter/in2p3.fr)



all "knowledge" but $\sin 2\phi_1$ (overlaid)

90% C.L. contour

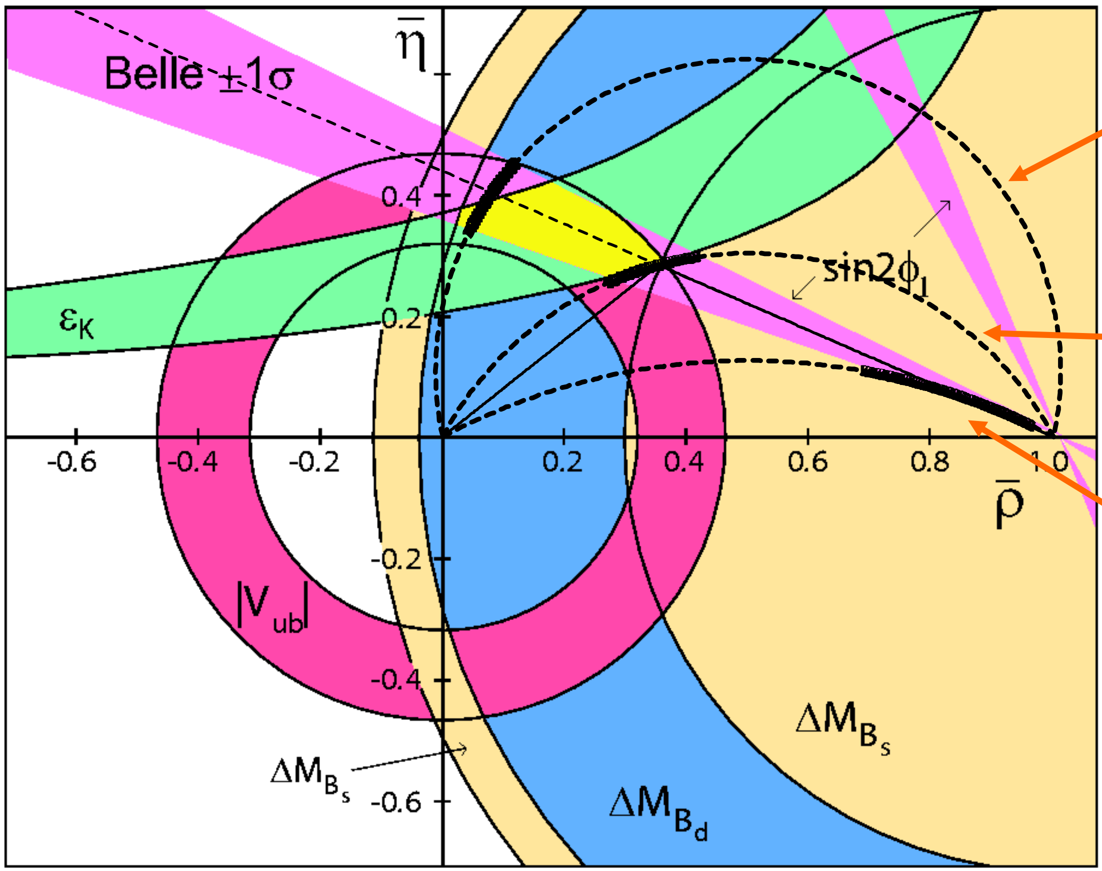


including $\sin 2\phi_1$

UT constraints

how about $\sin 2\phi_2$?

constraint determines arcs through $(\bar{\rho},\bar{\eta})=(0,0)$ and (1,0) with center and radius depending on ϕ_2;



$\phi_2=78^o$

$\phi_2=118^o$

$\phi_2=152^o$

95% C.L.

consistent with other measurem.

PDG values 2002 + Belle $\sin 2\phi_1$

(H.Sagawa,FPCP'03)

Summary

V_{ud}: $5x10^{-4}$ accuracy, theoretically limited, PIBETA

V_{us}: unitarity OK, disagreement in K_{e3} (E865), KLOE, NA48;

V_{cb}: excl. limited by $\mathcal{F}(1)$, moments will improve th.ambig.;

V_{ub}: q^2 dependence starting (Belle,Cleo); inclusive M_x, q^2 will be improved (Ba/lle); th. ambiguities resolved
- through tests of models (exclusive);
- through moments measurements ($b \to s\gamma$);

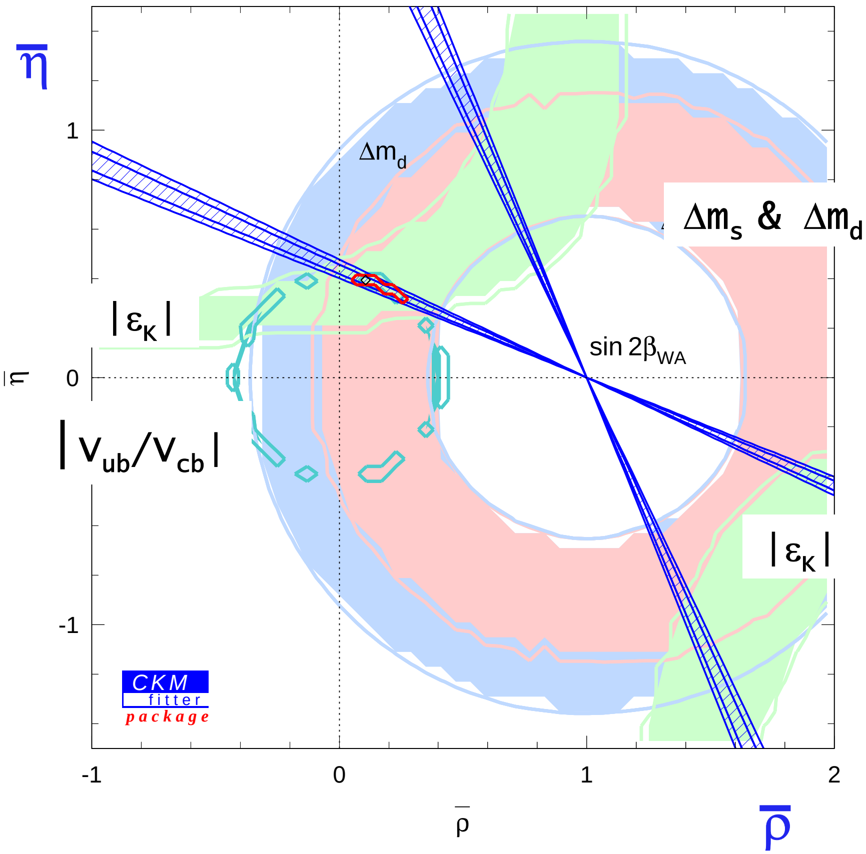
excl./incl. disagreement?

V_{td},V_{ts}: Δm_d already very precise, also improvement on τ_B; Δm_s important constraint on UT, domain of D0, CDF;

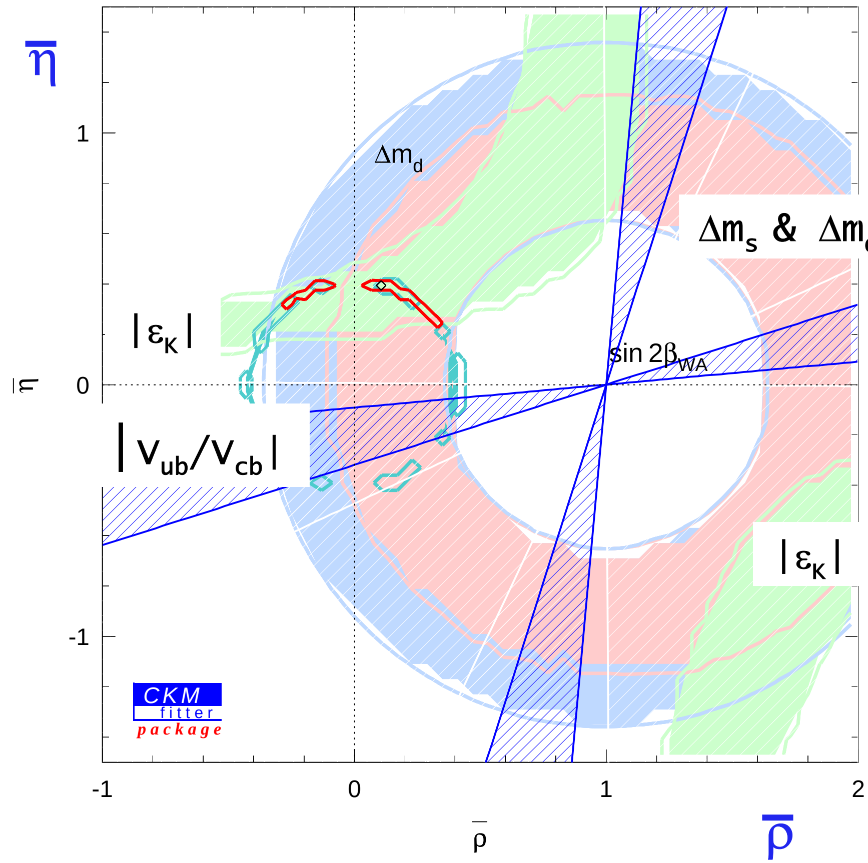
$\sin 2\phi_1$: real precision measurement, NP could be seen by Ba/lle (e.g. ϕK_s);

$\sin 2\phi_2$: just started, although complicated, will give important constraint on UT;

…to conclude



½ of current error on V_{ub}, $\sin 2\phi_1$ (400fb^{-1})

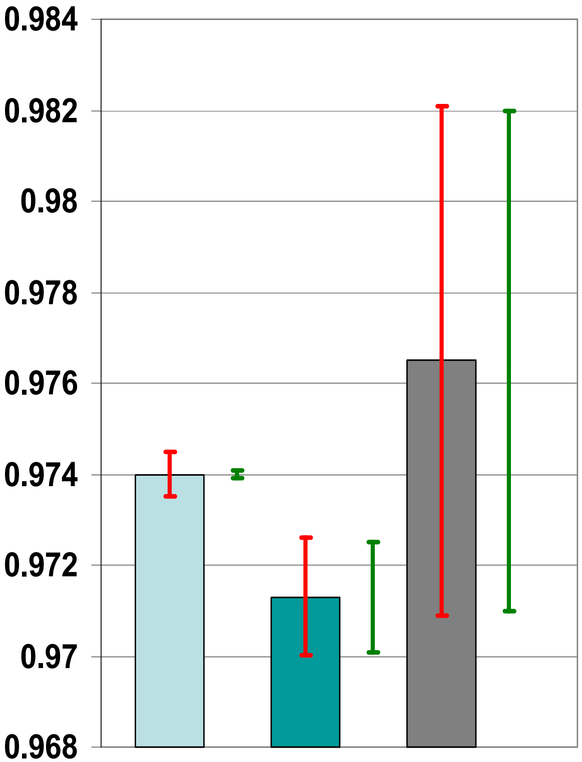


same with current $\sin 2\phi_1$ value from ϕK_s and ½ error

backup slide

V_{ud}, V_{us} summary

V_{ud}

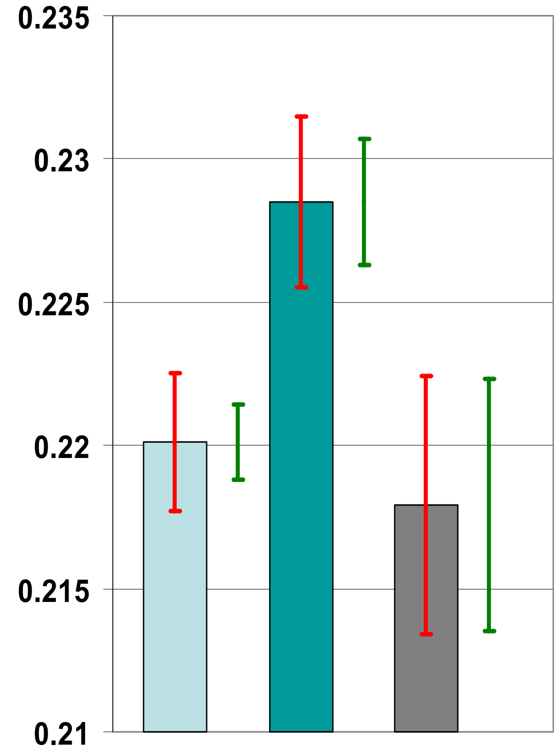


nuclear beta decay
(Hardy,Towner, Eur.Phys.J.A15(2002))

n beta decay PERKEO II Grenoble
(H.Abele et al., PRL 88(2002))

Pi beta decay PIBETA PSI
(D.Pocanic, CKM Workshop, Durham,2003)

V_{us}



Ke3 PDG

Ke3 E865
(E865,hep-ex/ 0305042)

Tau decay
(ALEPH,hep-ex/ 0211057)

KLOE, NA48

experimental error

experimental error ⊕ theor. uncertainty

- nucl.β decays ($1 \pm 5 \times 10^{-4}$) limited by th. uncertainty;
- important check expected from π β decays with ~1/2 error;

- new measurement by E865 vs. average of older, systematics under better control?
- new measurements coming;

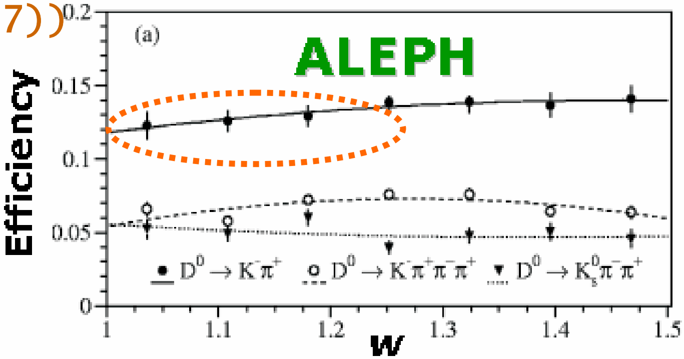
V_{cb} from $B \to D^* l \nu$

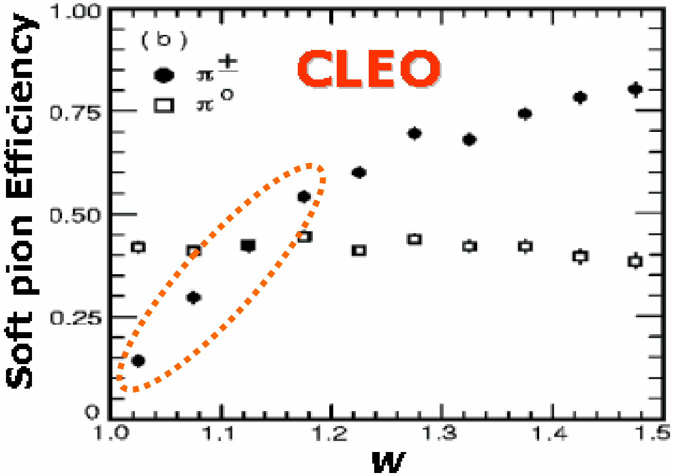
(Aleph,PLB395,373(97))

backup slide

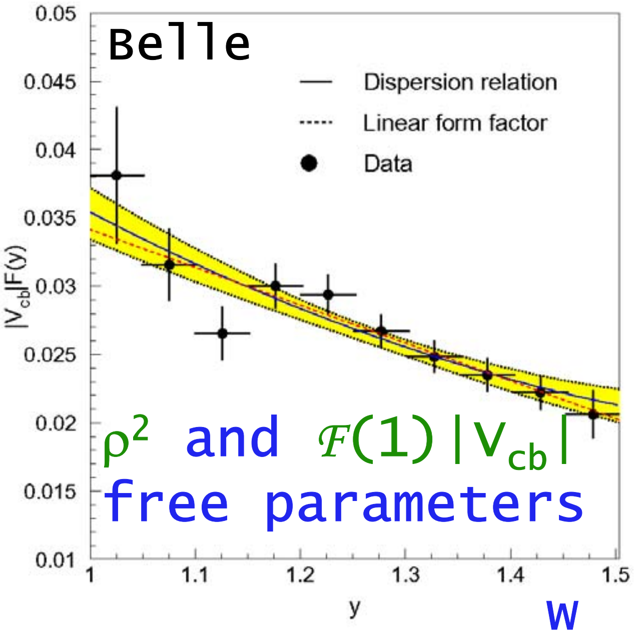
- w reconstruction $q^2=(p_l+p_\nu)^2$ p_{miss} (+ MC corrections) (Z^0)
  $\sigma(w)\sim 0.10$;

…or $q^2=(p_B-p_{D^*})^2$
$\sigma(w)\sim 0.03$;
also D** bckg. suppression $(\Upsilon(4s))$





(Belle,PLB526, 247(02))



ρ^2 and $\mathcal{F}(1)|V_{cb}|$ free parameters

- $\mathcal{F}(w)$ parametrization; single (slope) parameter ρ^2

$$\mathcal{F}(w) = \mathcal{F}(1)\mathcal{K}(w)\left(1-8\rho^2 z+\ldots+O(z^4)\right)$$

$$z=\frac{\sqrt{w+1}-\sqrt{2}}{\sqrt{w+1}+\sqrt{2}}$$

(I.Caprini et al., Nucl.Phys.B530,153(1998))

V_{cb} from $D^*l\nu$ by DELPHI

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$$Br(\bar{B}^0 \to D^{*+} l^- \bar{\nu}) = (4.70 \pm 0.13 \pm 0.34)\%$$

Syst. error dominated by D** w distribution modeling
(± 5.1% on V_{cb})

Two narrow states, D_1 & D_2^* (1+,2+) well established
$Br(B \to D_2^* l\nu)/Br(B \to D_1 l\nu) < 0.6$ @95% CL (LEP,CDF,SLD,CERN-EP/2001-050)

- agreement with HQET when $\mathcal{O}(1/m_c)$ corrections taken into account;
- use such model for form factors and vary relevant parameters in the range consistent with experimental results;
- syst. error is the max. difference from central value when $\mathcal{F}(1)V_{cb}$ measurement repeated for each parameter variation;

Moments from BaBar

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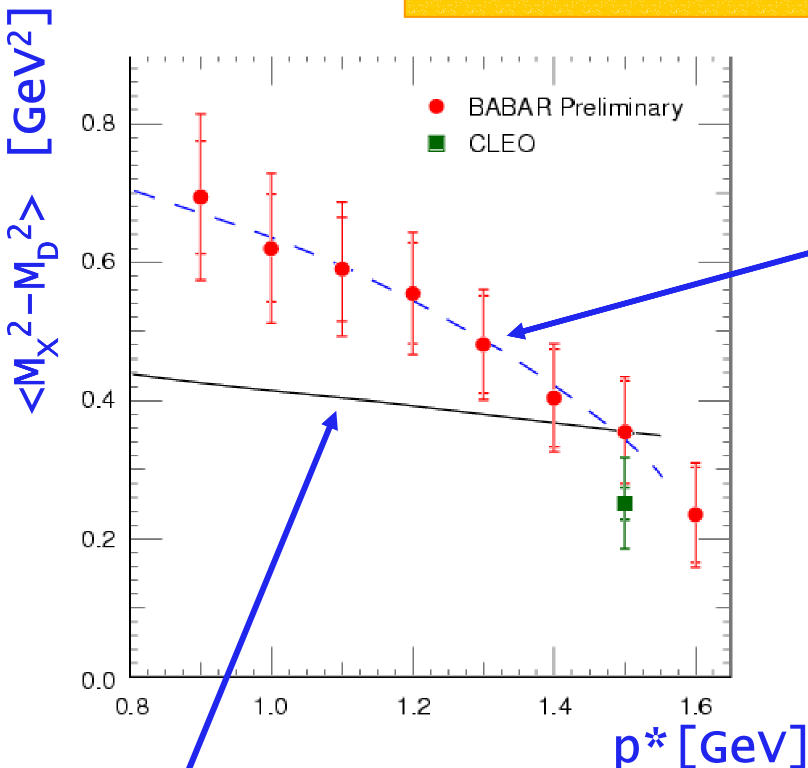


$\lambda_1, \bar{\Lambda}$ free

due to the fact

$$\langle M_X^2 - M_D^2 \rangle \geq f_{D^{**}}(M_{D^{**}}^2 - \bar{M}_D^2) + f_{D^*}(M_{D^*}2 - \bar{M}_D^2) + f_D(M_D^2 - \bar{M}_D^2)$$

?? excited state production saturated by D** ??

(M.Luke, CKM Workshop, Durham'03)

predicted dependence with $\lambda_1, \bar{\Lambda}$ as measured at p*=1.5 GeV

theoretical error similar to experimental

(N.Uraltsev, CKM Workshop, Durham'03)

new results expected

backup slide

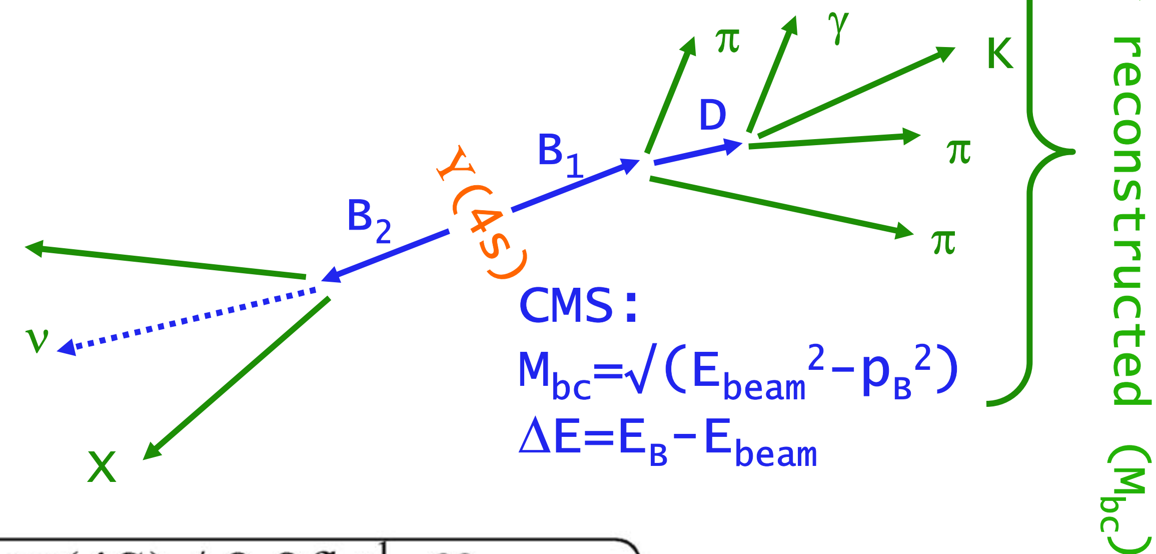
V_{cb} inclusive from Belle

fully reconstructed B:

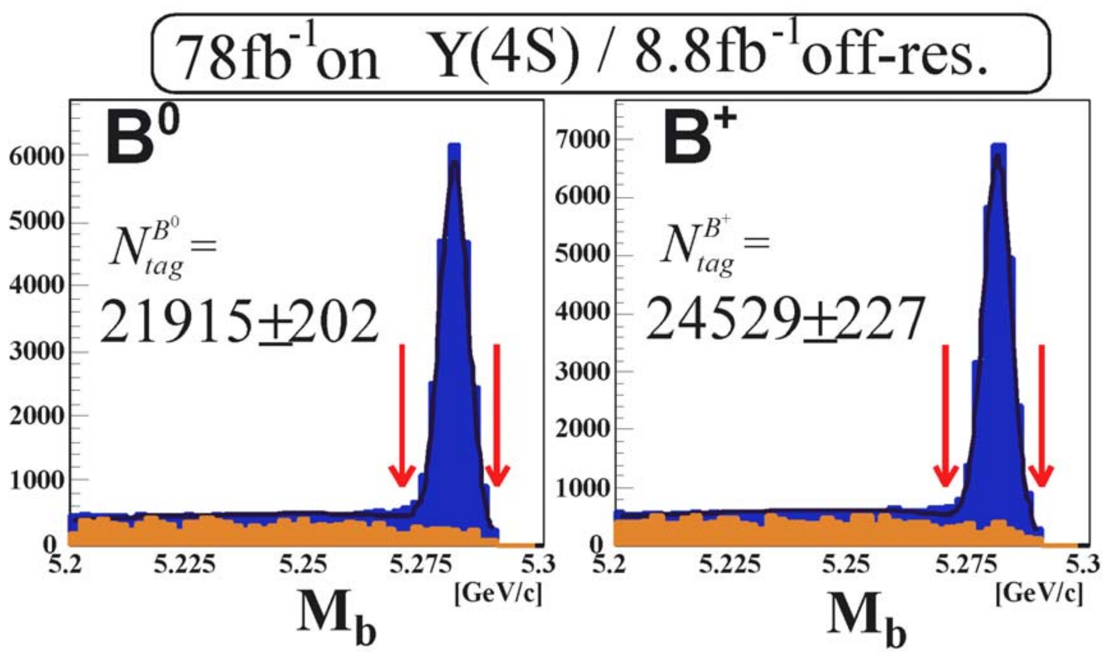
$B \to D^{(*)}\pi^{\pm}$, $D^{(*)}\rho^{\pm}$, $D^{(*)}a_1^{\pm}$;

$D^0 \to K\pi$, $K3\pi$, $K\pi\pi^0$, $K_s 2\pi$;

$D^{\pm} \to K2\pi$



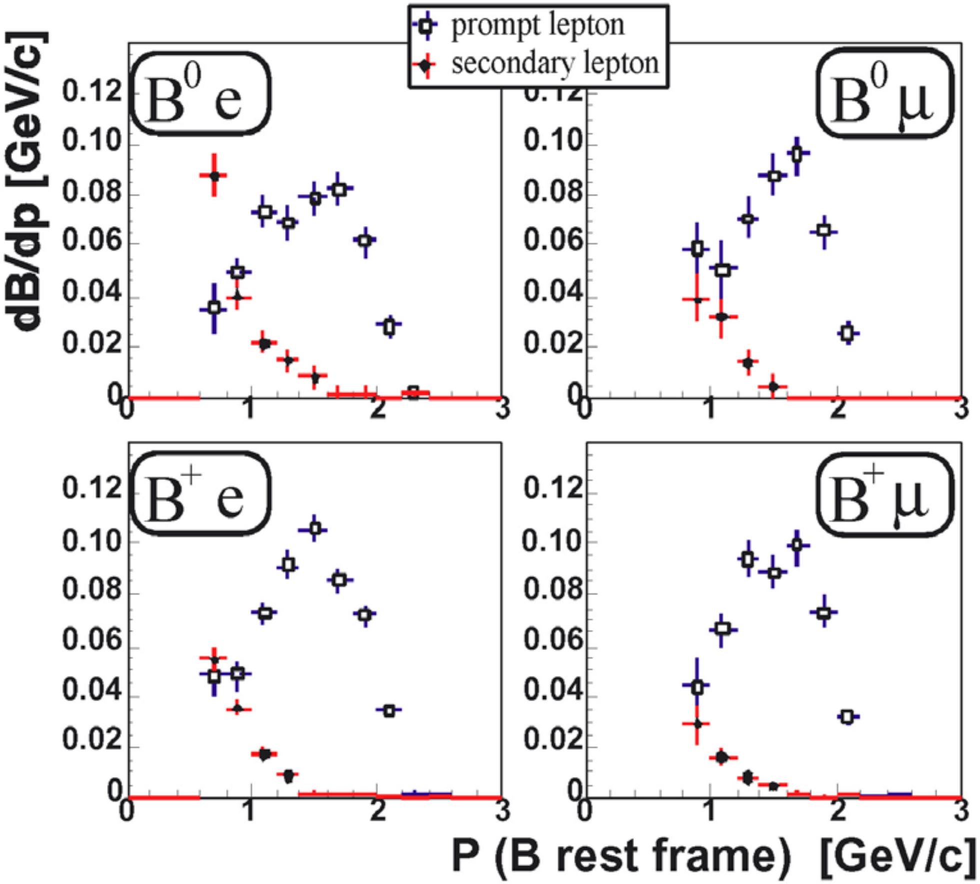
(Belle,DPF'03)



V_{cb} inclusive from Belle

backup slide

Lepton spectrum on semileptonic side:
(p*>0.6 GeV, extrap. to full interval)



individual Br (B^0,$B^\pm$,e,μ) measured

$Br(B \to Xl\nu)=$
$(11.19\pm0.20\pm0.31)\%$
stat. syst.
(PID ε,
extrap.)

(Belle,DPF'03)

V_{ub} exclusive from BaBar

backup slide

(L.H.Wilden, K.R.Schubert, BaBar, CKM Workshop, Durham'03)

- $B \to \pi^\pm, \pi^0, \rho^\pm, \rho^0, \omega\ e\nu$; $50 fb^{-1}$;
- two E_l regions: 2-2.3 GeV ($b \to cl\nu$ bckg.), 2.3-2.7 GeV (continuum bckg.);
- $|\cos\theta_{BY}|<1.1$, $Y=\rho+l$, rejects wrong comb.;
- continuum suppression (NN);
- isospin relations: $\Gamma(B^0 \to \rho^- e^+\nu)=2\Gamma(B^+ \to \rho^0 e^+\nu)$, $\Gamma(B^0 \to \pi^- e^+\nu)=2\Gamma(B^+ \to \pi^0 e^+\nu)$
  quark model relation: $\Gamma(B^+ \to \rho^0 e^+\nu)= \Gamma(B^+ \to \omega e^+\nu)$

- fit $\Delta E=E_{had}+E_l+p_{miss}-E_{beam}$ and $M_{had}=m(\pi\pi(\pi))$ (only ΔE for π modes)
  9 parameters: $Br(B \to \rho/\omega l\nu)$, $Br(B \to \pi l\nu)$,
  $b \to ul\nu$ feeddown (norm. in two E_l regions)
  inclusive (parton level calc. with param. from $B \to X_s\gamma$) + expected reson.
  $b \to cl\nu$ (norm. in each channel)
- extrapolate to entire E_l using 5 different form factors (LQCD, sum rules, quark models, HQET (relates B and D semil. modes))

$$Br(B \to \rho^- e^+\nu)=(3.29\pm0.42\pm0.47\pm0.55)10^{-4}$$

stat. syst. th.

largest single contrib.
-feed-down modeling;
-detector simul. (ν recon.)

full spread of central values for diff. form f.

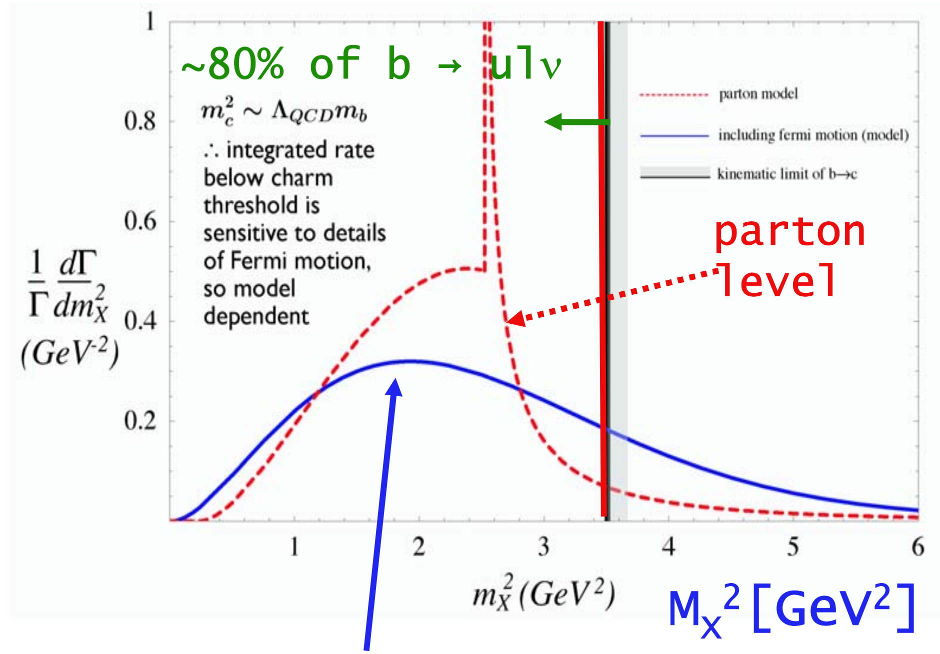
V_{ub} from inclusive decays

backup slide

(plot M.Luke, CKM Workshop, Durham'03)

Semileptonic width $b \to u l \nu$ sensitive to V_{ub} in analog way as $b \to c l \nu$ sensitive to V_{cb};

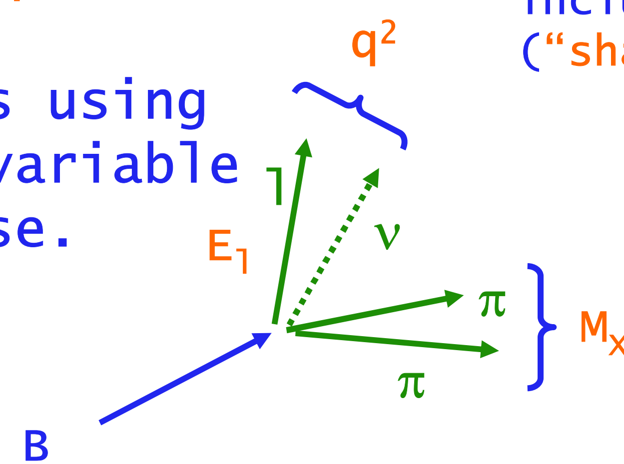
cuts ↔ larger th. uncertainty



Variables separating $b \to u l \nu$ from $b \to c l \nu$:

- lepton energy E_l;
- hadronic inv. mass M_X;
- leptonic inv. mass q^2;

Number of measurements using different individual variable or combination of those.



V_{ub} from lepton energy

backup slide

from Br to V_{ub}:

$$|V_{ub}| = 0.00445\,(1 \pm 0.052|_{1/m_b{}^3} \pm 0.020|_{pert})\sqrt{\frac{Br(B \to X_u \ell \nu)}{0.002}}\sqrt{\frac{1.55\,ps}{\tau_B}}$$

(N.Uraltsev et al., CKM Workshop, CERN'02)

$|V_{ub}| = (4.11 \pm 0.34 \pm 0.44 \pm 0.23 \pm 0.24)\times10^{-3}$ Cleo (rescaled)

$|V_{ub}| = (4.43 \pm 0.29 \pm 0.50 \pm 0.25 \pm 0.35)\times10^{-3}$ BaBar

$|V_{ub}| = (4.26 \pm 0.28 \pm 0.48 \pm 0.24 \pm 0.34)\times10^{-3}$ Belle

exp. → stat.+syst.; f_u → shape function; th. → above formula; $s\gamma$ → is shape function really same

➢ to extrapolate partial Br in limited momentum range to full range → need $b \to u l \nu$ model: parton level convoluted with shape function Fermi motion);

$$F(k_+) = N(1-x)^a e^{(1+a)x} \qquad x = \frac{k_+}{\bar{\Lambda}} \le 1$$

(F.De Fazio, M.Neubert, JHEP06,017(99))

(A.Sugiyama, Belle, Moriond'03)

Belle hadronic mass and q^2

backup slide

- lepton selection
- ν reconstruction
- pseudo reconstruction of B
- reconstruction of M_X and q^2

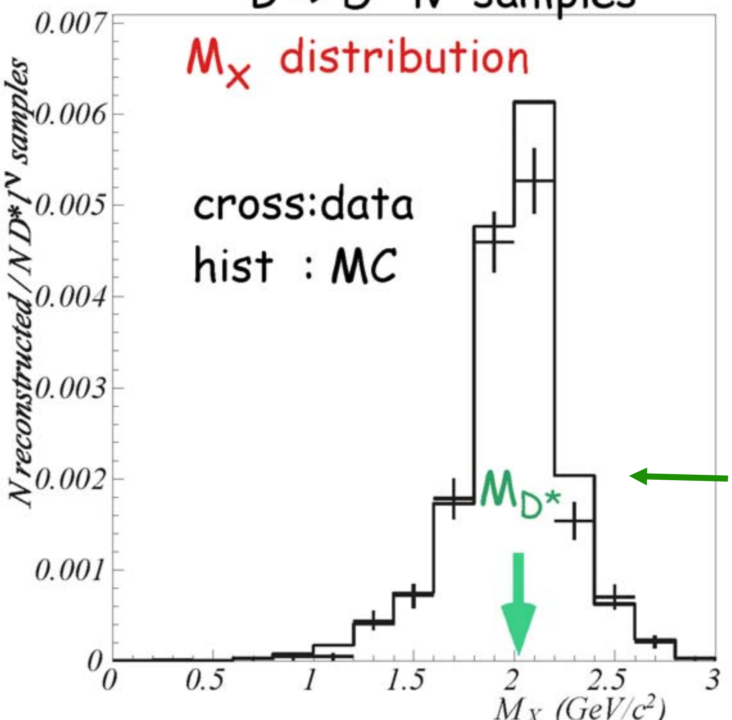
$$W = \frac{\mathcal{L}(random)}{\mathcal{L}(random) + \mathcal{L}(correct)}$$

minimization by exchanging particles (50 times);
different initial (random) W (10 times);
finally require W small enough;
reconstruct M_X and q^2;
signal region: $q^2>7$ GeV^2, $M_X<1.5$ GeV;

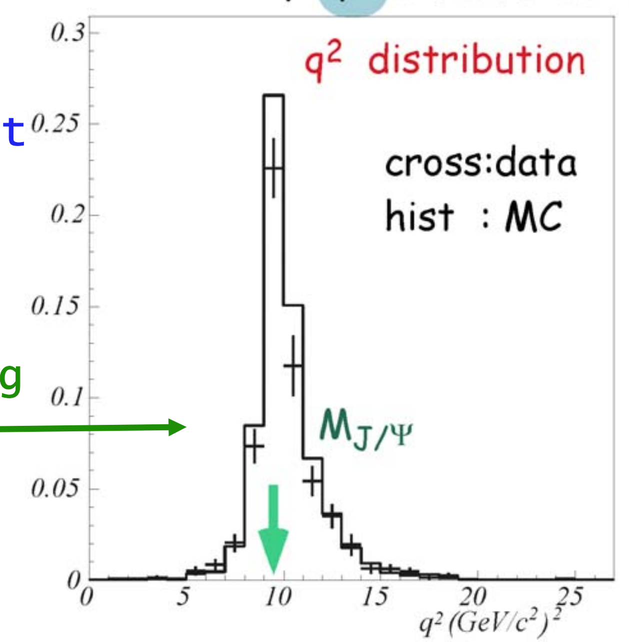
from MC:
multidimensional p.d.f. for correct and wrong comb.
composed of p_B^*, E_B^*, M^2_{miss},…

check of annealing quality

B -> D* lν samples



B ->J/Ψ X samples
→ l^+ l^- treated as ν



V_{cb}, V_{ub} summary

$V_{cb} = (42.6 \pm 1.2 \pm 1.9) \times 10^{-3}$ $D^* l \nu$

exp.   th.

th.error. $\mathcal{F}(1)$, in future LQCD?

$V_{cb} = (41.4 \pm 0.7 \pm 0.6) \times 10^{-3}$ inclusive

exp.   th.

exp. error will be reduced soon (moments), $1/m_b^4$

$V_{ub} = (3.42 \pm 0.22 \pm 0.55) \times 10^{-3}$ exclusive

exp.   th.

need official averaging procedure, test models

exp.   th.

$V_{ub} = (4.28 \pm 0.17 \pm 0.62) \times 10^{-3}$ lepton endpoint

more precise $b \rightarrow s\gamma$
different methods – th. consistency

B oscillations summary

Summary:

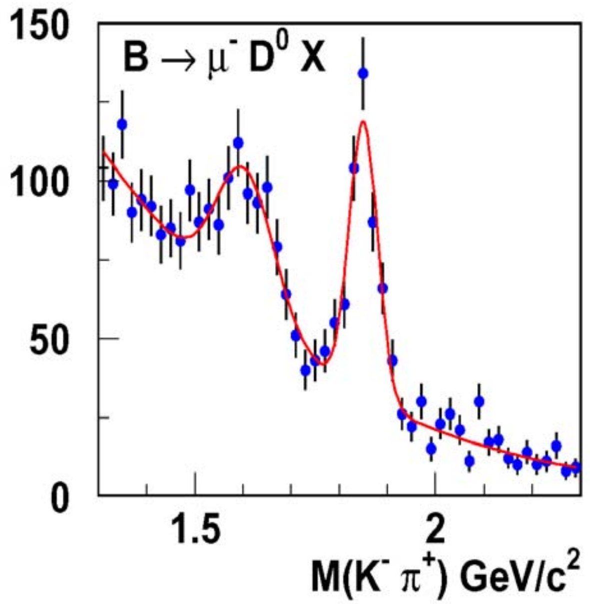
$\Delta m_d = 0.502\ (1 \pm 0.012)\ ps^{-1}$

Ba/lle:300fb^{-1} $\sigma \sim 0.04\%$
τ_B limiting factor;
(simultaneous fit);

$\Delta m_s < 14.4\ ps^{-1}$ @95% C.L.

next test of SM in CKM fits;
Tevatron domain until LHC;
e.g. D0 5σ sign. w/ 2fb^{-1}
@$\Delta m_s \sim 17ps^{-1}$;
CDF needs $\mathcal{O}(10^3)$ $B_s \to D_s^{(*)} n\pi$
for same;

$F_{Bd}\sqrt{B_{Bd}} \sim \pm 15\%$ in CKM fits
$F_{Bs}\sqrt{B_{Bs}} \sim \pm 15\%$
$\xi \sim \pm 6\%$



(V.Jain,D0,FPCP'03)

~450 $B \to D^0 \mu X/pb^{-1}$ → ~40 $B_s \to D_s \mu X/pb^{-1}$

backup slide

V_{td}, V_{ts}

From $B_{d,s}$ oscillations

R_t can be constrained using Δm_d

$$R_t = \sqrt{(1-\bar{\rho})^2 + \bar{\eta}^2} = 0.85\left[\frac{230MeV}{F_{Bd}\sqrt{B_{Bd}}}\right]\sqrt{\frac{\Delta m_d}{0.5\,ps^{-1}}}\sqrt{\frac{0.55}{\eta_B}}\sqrt{\frac{2.34}{S_0(m_t)}}\left[\frac{0.041}{|V_{cb}|}\right]$$

largest uncertainty

measured

or using $\Delta m_d / \Delta m_s$

$$R_t = 0.86\sqrt{\frac{\Delta m_d}{0.5\,ps^{-1}}}\sqrt{\frac{18.4\,ps^{-1}}{\Delta m_s}}\left[\frac{\xi}{1.18}\right] \qquad \xi = \frac{F_{Bs}\sqrt{B_{Bs}}}{F_{Bd}\sqrt{B_{Bd}}}$$

measurement

source of th. uncertainty

$\sin 2\phi_2 (\alpha)$

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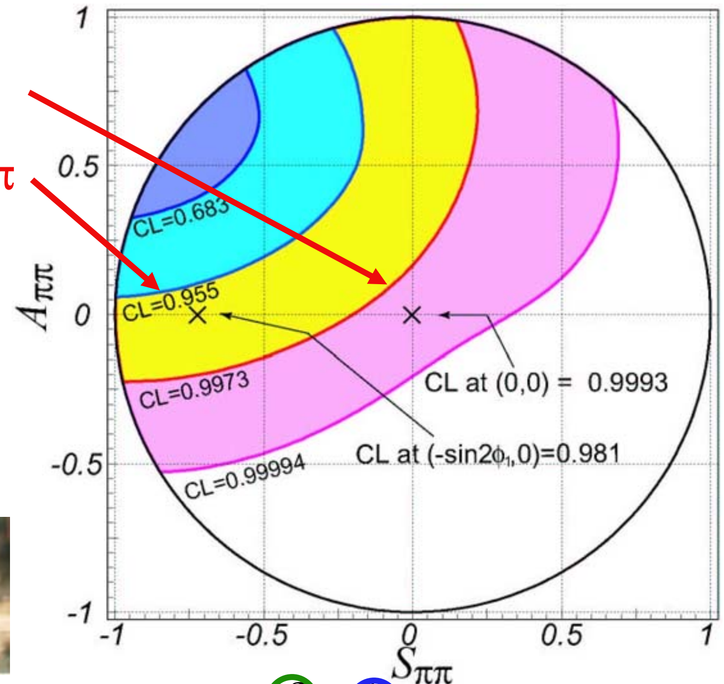
(3.4σ) CP in B → ππ

(2.2σ) direct CP in B → ππ



Interpretation:

tree level

tree + 

$$\lambda_{\pi\pi} = e^{2i\phi_2} \quad \rightarrow \quad \lambda_{\pi\pi} = e^{2i\phi_2} \frac{1+|P/T|\, e^{i\delta + i\phi_3}}{1+|P/T|\, e^{i\delta - i\phi_3}} \equiv |\lambda_{\pi\pi}|\, e^{2i\phi_{2eff}}$$

$$A_{\pi\pi} = 0 \quad \rightarrow \quad A_{\pi\pi} \propto \sin\delta$$

$$S_{\pi\pi} = \sin(2\phi_2) \rightarrow \quad S_{\pi\pi} = \sqrt{1 - A^2{}_{\pi\pi}}\, \sin(2\phi_{2eff})$$

strong phase diff. P-T

weak phase (changes sign)

direct CP

$\sin 2\phi_2 (\alpha)$

backup slide

ϕ_{2eff} depends on δ, ϕ_3, ϕ_2 and |P/T|

$\pi = \phi_1 + \phi_2 + \phi_3 \rightarrow \phi_{2eff}$ depends on δ, ϕ_1, ϕ_2 and |P/T|

penguin amplitudes $B \to K^+\pi^-$ and $B \to \pi^+\pi^-$ are equal
→ limits on |P/T| (~0.3);
considering all interval of δ values one can obtain interval of ϕ_2 values;

isospin relations can be used to constrain δ
(or better to say $\phi_2 - \phi_{2eff}$);

UT constraints

backup slide

Comparison of V_{ub} values

theoretical uncertainty:

constant C.L.

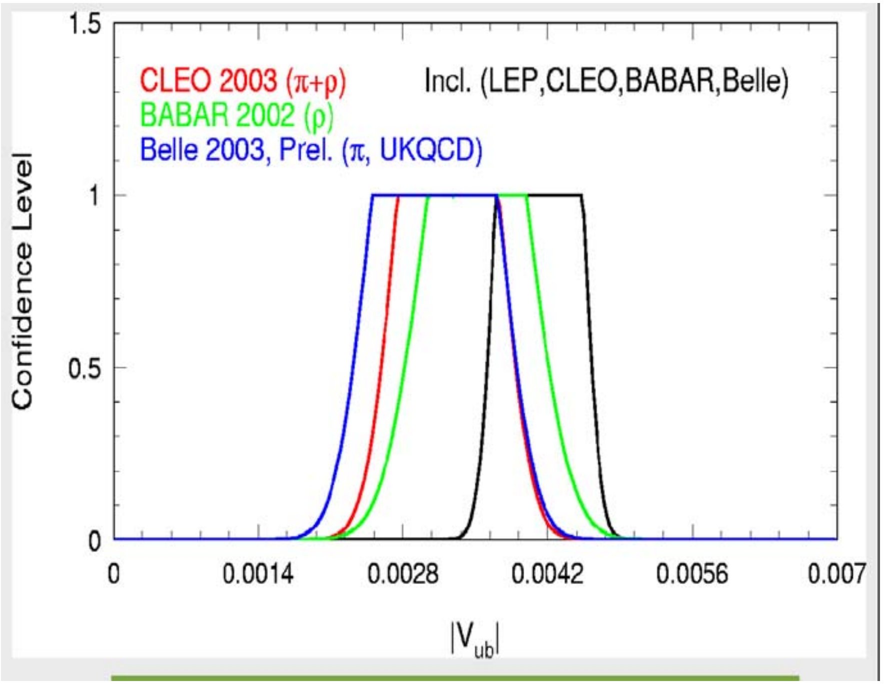
exclusive/inclusive

consistentcy

$V_{ub}^{excl} - V_{ub}^{lepton} =$

$0.86 \pm 0.28 \pm ???$

exp. uncorr.th.



(H.Lacker,FPCP'03)

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Rfit

(A.Hoecker et al.,Eur.Phys.J.C21,225(01))

Th. quantities – "reasonable range",
not statistically distributed,
frequentist approach;

$$\chi^2 = -2\ln\mathcal{L}(y_{\text{mod}})$$

th. predictions, depending on model parameters y_{mod}

$$\mathcal{L}(y_{\text{mod}}) = \mathcal{L}_{\exp}(x_{\exp} - x_{theo}(y_{\text{mod}}))\cdot\mathcal{L}_{theo}(y_{QCD})$$

knowledge on th. para.

$$y_{QCD} \in y_{\text{mod}}$$

$$\mathcal{L}_{theo} = \begin{cases} 1, & y_{QCD} \in R \\ 0, & y_{QCD} \notin R \end{cases}$$

allowed range of th.param.

uniform $\mathcal{L}_{theo}$ ≠ uniform p.d.f.

$$\mathcal{L}_{theo}(|V_{cb}|^4) = 1, \quad |V_{cb}| \in R$$

$$p.d.f.(|V_{cb}|) = konst. \Rightarrow p.d.f.(|V_{cb}|^4) \propto |V_{cb}|^{-3/4}$$

minimization:

$$\chi^2 = -2\ln\mathcal{L}(y_{\text{mod}}) \Rightarrow \chi^2{}_{\min;y_{\text{mod}}}$$

CL built from MC simulations;
generation of pseudo exp. with optimal y_{mod} using $\mathcal{L}_{exp}$;