CKM from semi-leptonic B decays

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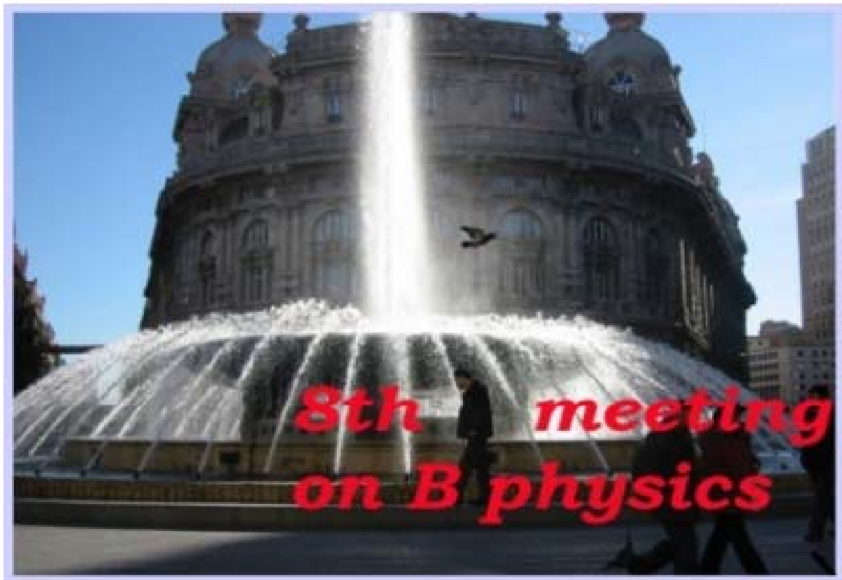
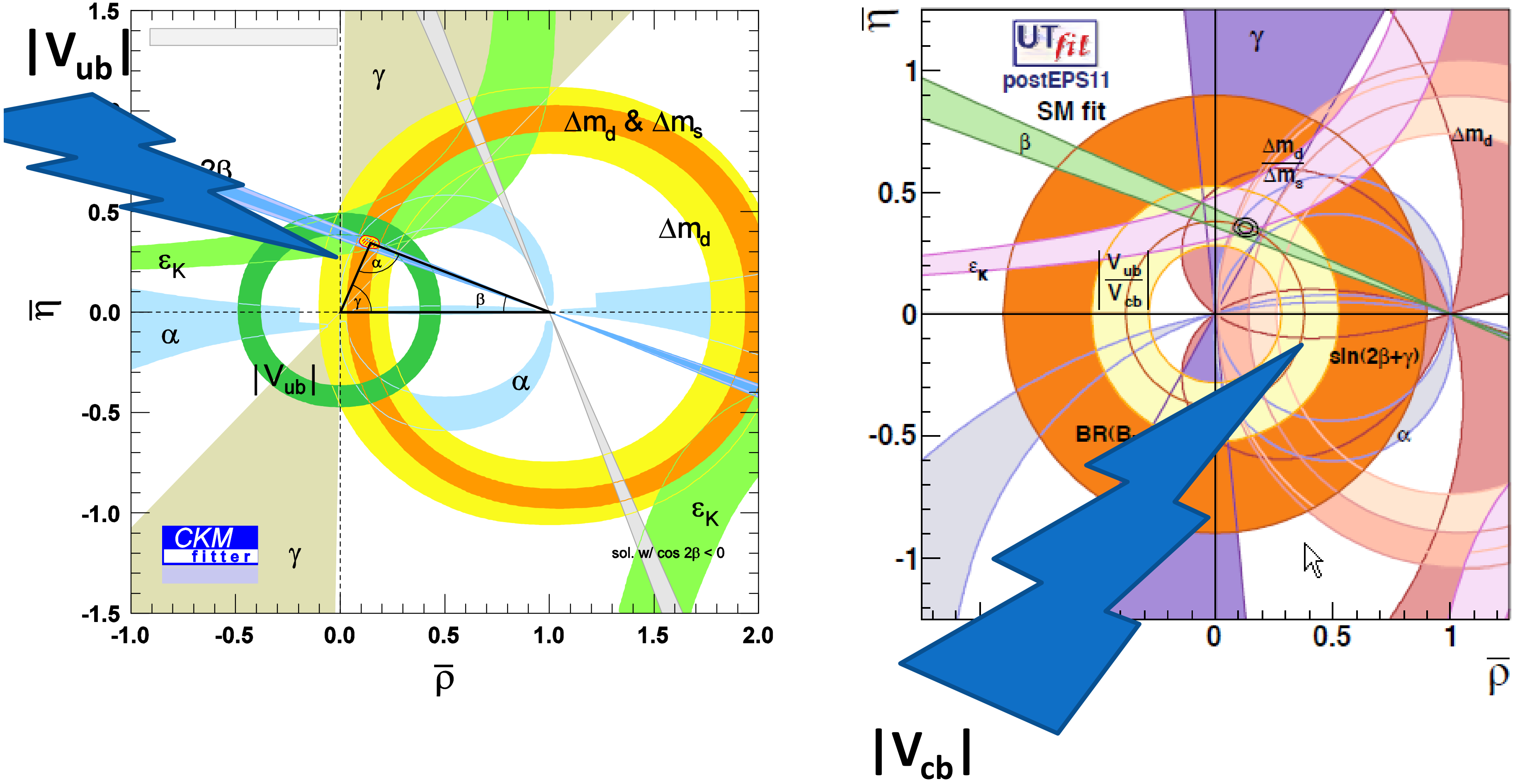
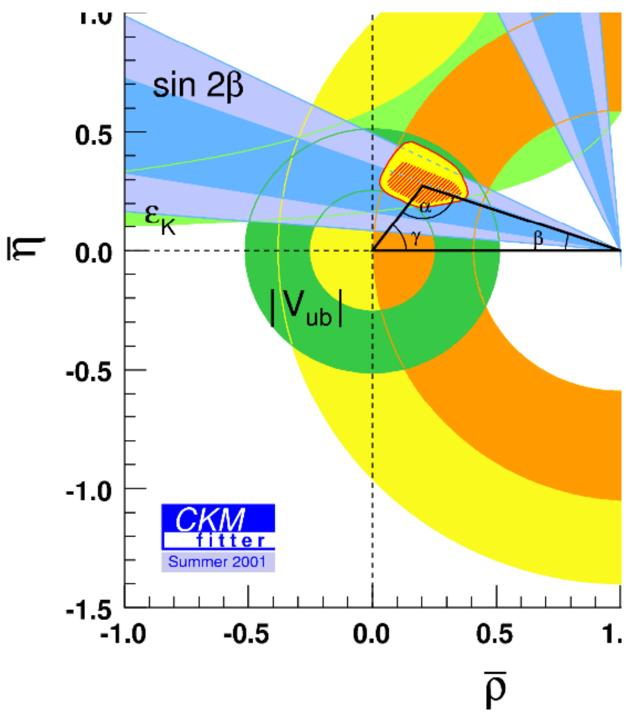


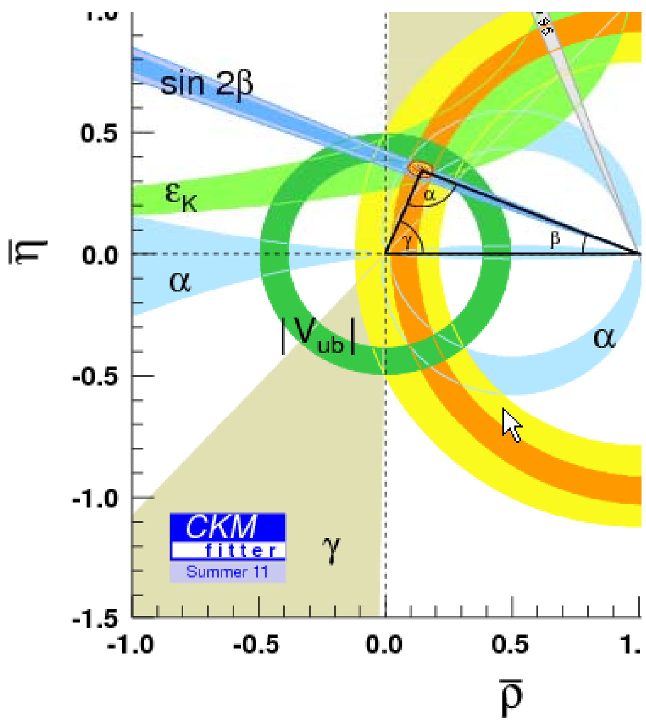
B_d Unitarity triangle



Outline

- |Vub| and |Vcb| estimated through SL decays
- Crucial input also for NP sensitive other estimates, f.i ε_K **= f(|Vcb|)**
- |Vub| possibly extracted from NP sensitive $B^+ \to \tau^+ \nu$
- Some recent progress in inclusive and exclusive results





Exclusive $B \to D/D^* \ell \nu$ decays

- Form Factors (FF) : non perturbative evaluation main theoretical uncertainty

$$\frac{d\Gamma(\bar{B} \to D l \bar{\nu})}{dw} \propto (w^2 - 1)^{3/2} |V_{cb}|^2 |\mathcal{G}(w)|^2 \qquad \frac{d\Gamma(\bar{B} \to D^* l \bar{\nu})}{dw} \propto (w^2 - 1)^{1/2} |V_{cb}|^2 |\mathcal{F}(w)|^2$$

$w = v_B \cdot v_D \geq 1 \quad w_{max} \simeq 1.5$ related to the energy of the outgoing $D^{(*)}$

- FF are predicted to be 1 in the limit of
  - ω= 1 (zero recoil point, with leptons back to back and mesons at rest)
  - Infinite mass limit for both *b* and *c*

On theory side, calculate deviations from unity at ω= 1 (lattice vs sum rules)

- $|Vcb|^2$ x FF is fitted from data at ω different from zero (due to vanishing of phase space at zero recoil point) and then extrapolated to ω= 1

Lattice results

- Recent results for $B \to D^*$ from **unquenched Fermilab/MiLC in 2+1 flavour** (CKM 2010)

$$F(1) = 0.908 \pm 0.17$$

$$|V_{cb}| F(1) \times 10^3 = 36.04 \pm 0.52$$

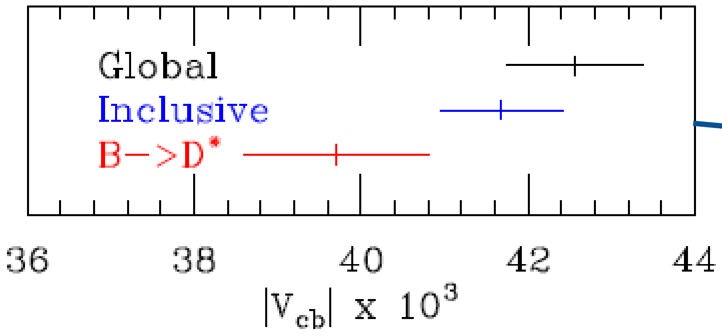
HFAG end of 2009 update

$$|V_{cb}| = 39.7(7)(7) \times 10^{-3}$$

syst

stat

- results shows 1.6 σ disagreement with the inclusive determination



HFAG 2011

Global: all inputs excluded $|V_{bc}|$ (Laiho, Lunghi, Van de Water (LLV) [arXiv:0910.2928])

- For B -> D **unquenched Fermilab/MILC in 2+1 flavour** (hep-lat/0409116)

$$\mathcal{G}(1) = 1.074 \pm 0.018 \pm 0.016$$

- $\mathcal{G}(1)|V_{cb}| = (43.0 \pm 1.9 \pm 1.4) \times 10^{-3}$ (Babar arXiv:0904.4063)

$$|V_{cb}| = (39.8 \pm 1.8 \pm 1.3 \pm 0.9_{FF}) \times 10^{-3}$$

- By using a quenched lattice calculation based on the **Step Scaling Method** (relatively small model dependence, avoiding the large extrapolation to ω= 1) (de Divitiis et al., arXiv:0707.0582 [hep-lat])

$$|V_{cb}| = (41.6 \pm 1.8 \pm 1.4 \pm 0.7_{FF}) \times 10^{-3}$$

- Work in progress in the **unquenched Fermilab/MILC** analysis: methods, statistical errors, and parameter coverage (arXiv: 1111.0677)

Non-Lattice FF estimates

- $B \rightarrow D^*$ (Gambino, Mannell, Uraltsev. 1004.2859 [hep-ph])
  - Based on Zero Recoil Sum Rules
  - Including full α_s and up to $1/m_b^5$

$$\mathcal{F}(1) = 0.86 \pm 0.04$$

- $B \rightarrow D$ (Uraltsev hep-ph/0312001)
  - Based on "BPS" (Bogomol'nyi-Prasad-Sommerfield) limit
  OPE parameters: $\mu_\pi^2 = \mu_G^2$

$$\mathcal{G}(1) = 1.04 \pm 0.02$$

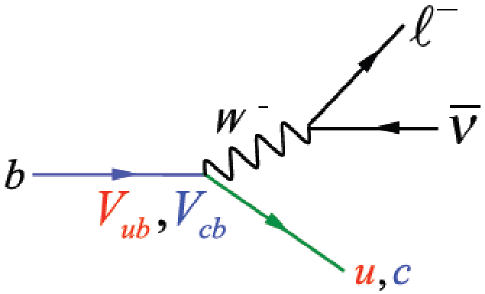
(motivation: rather close values obtained from experiment in inclusive B decay)

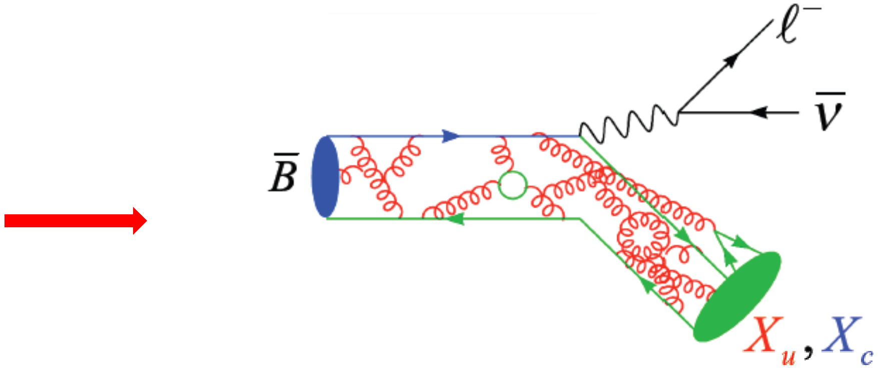
- Results are in better agreement with inclusive decays

$$V_{cb,excl} = (41.0 \pm 1.5) \times 10^{-3}$$

(Mannel, FPCP 2010)

Inclusive decays





- OPE factorization of short and long distance dynamics
  (m_b much larger than any scale in the matrix elements)
  - Nonperturbative input given by matrix elements of local operators
  - Coefficients of the operators perturbatively calculated
- parameterization of heavy quark dynamics by means of Heavy Quark Expansion (HQE)
  - double series in α_s and Λ/m_b

HQE

- Sketchily (also for differential rates)

$$\Gamma(B \to X_q l\nu) = \frac{G_F^2 m_b^5}{192\pi^3}|V_{qb}|^2 \left[c_3 < O_3 > + c_5 \frac{< O_5 >}{m_b^2} + c_6 \frac{< O_6 >}{m_b^3} + O\left(\frac{1}{m_b^4}\right)\right]$$

- c_i short distance, perturbative, calculable exp. in α_s

- $\langle O_i \rangle$ non-pert. matrix elements of local operators
  - dependence on quark masses and HQE parameters
    (2 parameters at $O(1/m_b^2)$,
    Chromomagnetic moment
    Kinetic energy

$$\mu_G^2 = \frac{< B|\bar{b}\,\frac{i}{2}\sigma^{\alpha\beta}G_{\alpha\beta}\,b|B >}{2M_B}$$

$$\vec{\mu}_\pi^2 = \frac{< B|\bar{b}\vec{\pi}^2 b|B >}{2M_B}$$

    2 more at $O(1/m_b^3)$...72 at $O(1/m_b^6)$...)
  - quark masses defined in a chosen scheme (1S, kinetic, ...)

Some recent th improvements in inclusive $b \to c\, l\, \nu$

- Tree level terms up to and including $1/m_b^5$ [Mannel et al. arXiv:1009.4622]
- $O(\alpha_s^2)$ corrections to the partonic differential rate
  [Biswas et al. arXiv:0911.4142; Melnikov arXiv:0803.0951; Dowling et al. arXiv:0809.0491; Pak et al. arXiv:0803.0960]
- Short distance μ_π^2 at order $O(\alpha_s)$ (μ_G^2 still at tree level): negligible effect on |Vcb| [Becher et al. arXiv:0708.0855]
- Term involving inverse powers of mc (Intrinsic charm) : $1/m_c^2\ 1/m_b^3$ [Bigi et al. arXiv:0911.3322]

Under the way:

- Short distance μ_G^2 at order $O(\alpha_s)$ (in case of radiative decays effect of about 20% on coefficients) , intrinsic charm and weak annihilation contributions
- reaching th uncertainty at the level of one percent.

|Vcb| determination Strategy

- measure spectrum + as many moments as possible
- Fit to HQE parameters, quark masses and $|V_{cb}|$

Latest Fits

Exp Th

	Hadronic moments	Mass-energy moments
$\lvert V_{cb}\rvert\ (10^{-3})$	$42.05 \pm 0.45 \pm 0.70$	$41.91 \pm 0.48 \pm 0.70$
m_b (GeV)	$4.549 \pm 0.031 \pm 0.038$	$4.556 \pm 0.034 \pm 0.041$

BaBar: simultaneous fit (kinetic scheme) to 12 hadronic mass moments (or 12 combined mass-energy moments), 13 lepton energy moments (including partial branching fractions as 'zero order' moments), and 3 photon energy moments in $B \longrightarrow X_s\ \gamma$ (arXiv:0908.0415)

	Kinetic scheme	1S scheme
$\lvert V_{cb}\rvert\ (10^{-3})$	41.58 ± 0.90	41.56 ± 0.68

Belle: 14 moments of the lepton energy spectrum, 7 hadronic mass moments and 4 moments of the photon energy spectrum in in $B \longrightarrow X_s\ \gamma$ (hep-ex/0611044)

HFAG global fit (kinetic scheme):

BaBar, Belle, CLEO, CDF and DELPHI (66 meas.)

Input	$\lvert V_{cb}\rvert$ (10^{-3})	m_b^{kin} (GeV)	μ_π^2 (GeV^2)
all moments	$41.85 \pm 0.42 \pm 0.09 \pm 0.59$	4.591 ± 0.031	0.454 ± 0.038
$X_c\ell\nu$ only	$41.68 \pm 0.44 \pm 0.09 \pm 0.58$	4.646 ± 0.047	0.439 ± 0.042

The first error on is the uncertainty from the global fit, the second is the error in the average B lifetime and the third error is an additional theoretical uncertainty

NOTE: The kinetic scheme fitting routines are now undergoing a major upgrade, concerning the inclusion of higher order effects, the possibility to change the perturbative scheme, and the inclusion of additional constraints in the fit (e.g. independent m_c to fix m_b)

(Gambino, arXiv:1102.0210)

UTfit	$(41.17 \pm 0.43)\ 10^{-3}$	SM fit summer 2010 (pre-ICHEP)
CKMfitter	$(40.7^{+0.19}_{-0.13})\ 10^{-3}$	Lepton-photon 2011

$B \to \pi \ell \nu$: $|V_{ub}|$ Exclusive determination

$$\frac{d\Gamma(\overline{B}^0 \to \pi^+ \ell \bar{\nu})}{dq^2} = \frac{G_F^2 |\vec{p}_\pi|^3}{24\pi^3} |V_{ub}|^2 \, |f_+(q^2)|^2$$

theoretical predictions for the FF split into two parts:
FF normalization at $q^2 = 0$ & functional form of the $\mathbf{q}^2$ dependence

Once again

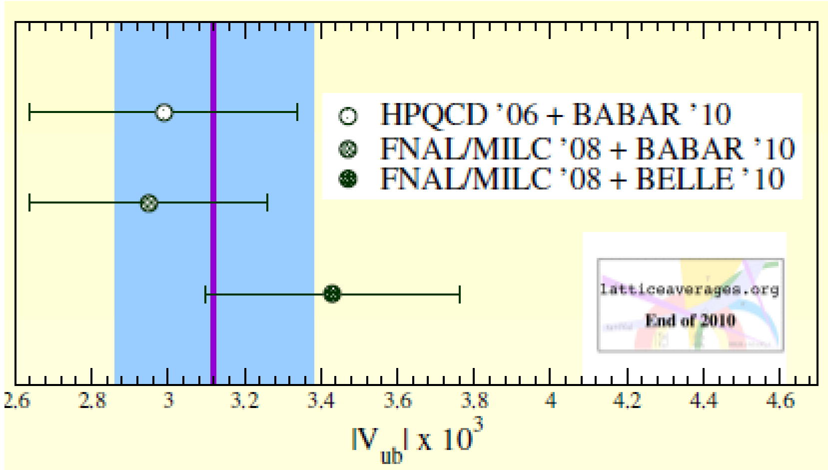
Lattice: high q^2 regions $q^2 > 16$ GeV^2

QCD Light Cone Sum Rules: complementary information
low q^2 regions $0 < q^2 < q^2$ max (q^2 max = 12 or 16 GeV^2)
→ analytically continue to higher value

Lattice

Two parameterizations for FF shape in q^2:

- z-expansion (Arnesen et al., Boyd, Grinstein, Lebed), based on analyticity, unitarity, and HQ symmetry (used with FNAL/MILC data)
- Becirevic Kaidalov (BK) parameterization, 3-parameters description given by the M_{B^*} pole (used with **HPQCD** data)



$$|V_{ub}^{exc.}|^{\textbf{LLV}} = (3.12 \pm 0.26) \times 10^{-3}$$

Laiho, Lunghi, Van de Water (LLV) 2010

www.latticeaverages.org

include only Nf=2+1

100% correlation is taken for the

theory/experimental errors in calculations

using the same lattice/exp. data.

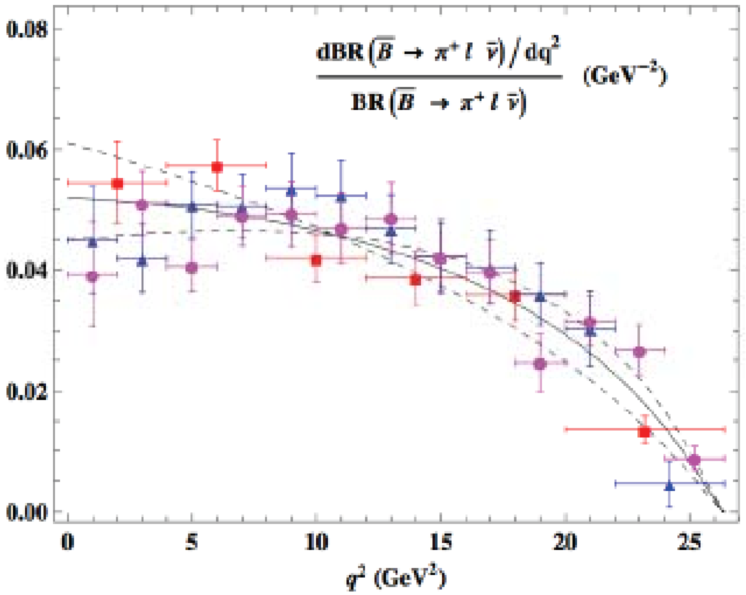
3.3 σ discrepancy

with inclusive calculations

QCD Light Cone Sum Rules

latest update of estimates in the full kinematic regions (z-parameterization): error down to 10%

Khodjamirian, Mannell, Offen, Wang 2011



(colour online) The normalized q^2-distribution in $B \to \pi l \nu$ obtained from LCSR and extrapolated with the z-series parameterization (central input- solid, uncertainties -dashed). The experimental data points are from BABAR: (red) squares [1], (blue) triangles [2] and Belle [3]: (magenta) full circles.

$$|V_{ub}| = (3.50^{+0.38}_{-0.33}\big|_{th.} \pm 0.11\big|_{exp.}) \times 10^{-3}$$

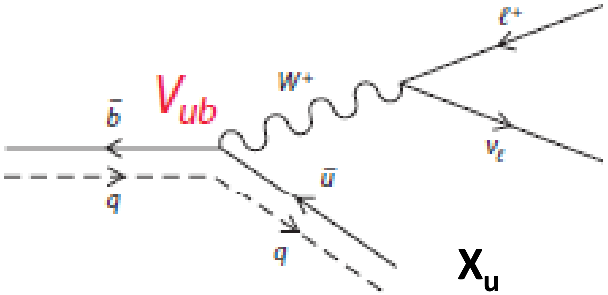
agreement with lattice

still lower than

inclusive determination

$|V_{ub}^{incl}| = (4.34^{+0.22}_{-0.27}) \times 10^{-3}$ HFAG, 1010.1589

Inclusive $|V_{ub}|$



large $b \to c$ background ($|V_{cb}/V_{ub}|^2 \approx 100$)

Need experimental phase space cuts to reduce background; in general

$$m_X \ll E_X$$

Phase space regions where OPE fails become dominant; new unwelcome effects (with respect to semileptonic $b \to c$):

- Final gluon radiation strongly inhibited: soft and collinear singularities
- perturbative expansion of spectra affected by large logarithms

  $$\alpha_s^n \log^{2n}(2\, E_X/m_X)$$

  to be resummed at all orders in PT
- non-perturbative effects related to a small vibration of the b quark in the B meson (Fermi motion) enhanced at $m_X^2 \approx \Lambda_{QCD}\, E_X$

Possible routes

- Enlarge experimental range
  - Belle results 09 access 90% data, claimed overall uncertainty of 7% on |Vub|

- Enlarge theoretical prospective

from HFAG

  - predictions based on parameterizations of shape function, and OPE constraints
  - BLNP Bosch, Lange, Neubert , Paz
  - GGOU Gambino, Giordano, Ossola, Uraltsev
  - predictions based on resummed pQCD
  - DGE Dressed Gluon Exponentiation Andersen, Gardi
  - ADFR Aglietti, Di Lodovico, Ferrera , Ricciardi

non HFAG global fit of shape function, $|V_{ub}|$ and m_b (also data on $B \to X_s \gamma$)

SIMBA Tackmann, Lacker, Ligeti, Stewart…

Shape function and resummed pQCD, qualitatively

- Shape function approach
  - in the threshold region inclusive description is still possible, with the introduction of a non perturbative distribution function (shape function)
  - at leading order is universal
  - Subleading shape functions are difficult to constrain and are not process independent
- ADFR approach:
  - introduce nonperturbative effects by an effective, infrared-safe, low energy QCD coupling constant, which mimics, in this specific threshold framework, non perturbative Fermi motion effects
  - the coupling is universal (radiative decay processes as well as B fragmentation processes)
  - no free parameters; the whole fragmentation process is inserted in a perturbative framework automatically IR regulated

Some th issues

- Unlike resummed pQCD, the OPE does not predict the shape function, ansatz needed for its functional form (About 100 forms considered in GGOU)

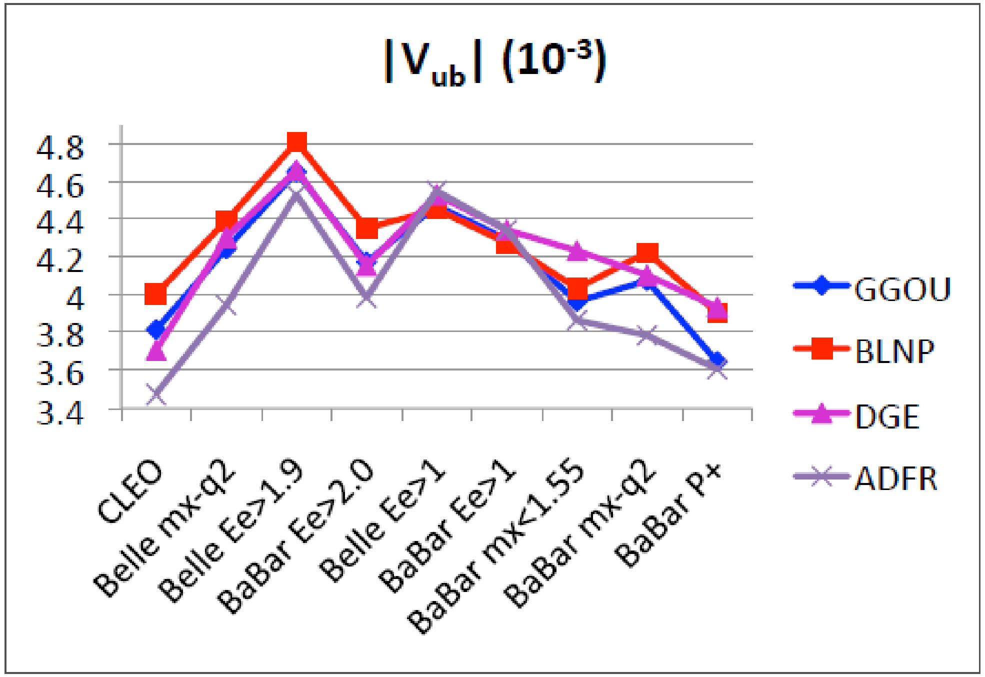
- Shape function approach established in different contexts and allows systematic improvements (recent NNLO corrections BNLP
  [Greub, Neubert, Pecjak arXiv:0909.1609])

- pQCD approaches connects B decays and B fragmentation; more predictive, but more rigid (ADFR→ change of the model effective coupling)

- Weak annihilation diagrams may pollute all present estimates and tend to decrease the extracted V_{ub}
  estimated at most a 2% effect at the level of the total rate
  [Ligeti et al. arXiv:1003.1351, Gambino et al arXiv:1004.0114]

Comparison with experiments

- Spread among calculations comparable to quoted theoretical (non-parametric) errors
- Not listed 2009 NNLO perturbative terms for BLNP (increase $|V_{ub}|$ by ~8%)

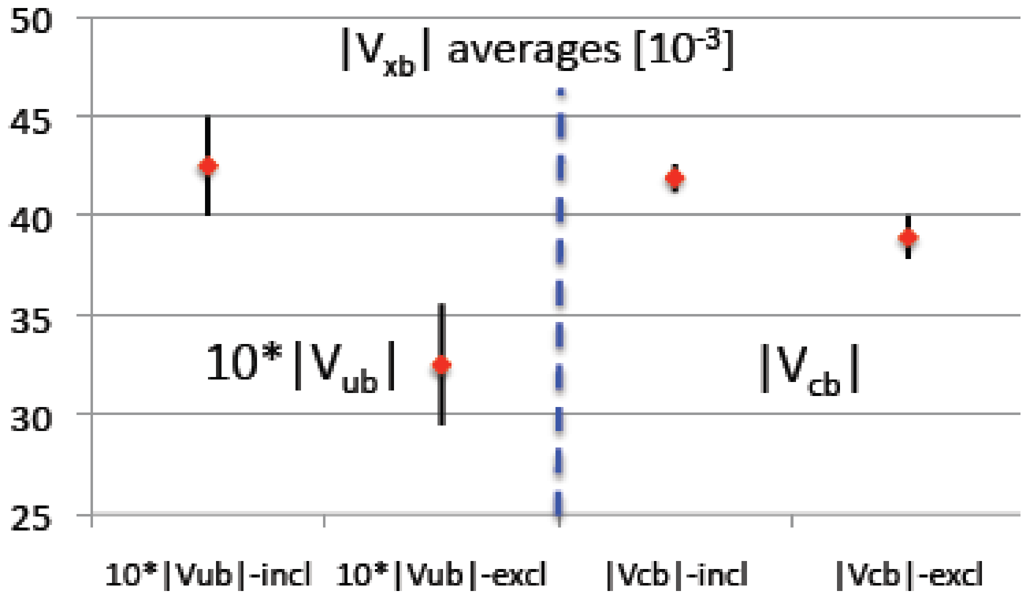


Kowalewski , Beauty 2011

$$|V_{ub}^{incl}| = (4.34^{+0.22}_{-0.27}) \times 10^{-3}$$ HFAG, 1010.1589

WHAT VALUE FOR $|V_{ub}|$?

- Inclusive determination systematically higher than exclusive



Kowalewski , Beauty 2011

V_{ub}incl- V_{ub}excl = 1.10 ±0.42

2.6 σ

Bernlocher, FPCP2011

- Indirect determination through UT fit (includes direct measurements as well as indirect) prefers lower central value

UTfit	$(3.64 \pm 0.11)\ 10^{-3}$	SM fit summer 2010 (pre-ICHEP)
CKMfitter	$(3.5^{+0.46}_{-0.22})\ 10^{-3}$	Lepton-photon 2011

Experimental future? SuperFlavors

- B factories unique in studying $|V_{ub}|$: BB pair alone (vs many particles not associated with the two b hadrons in LHC-b)
  - exploiting quantum correlation $\Upsilon(4S) \rightarrow BB$
  - Method: fully reconstruct one the two B's in hadronic mode (Breco)--obtain a high purity Bbeam on the opposite side (B recoil)
  - (almost) completely eliminate continuum background
  - unique to study rare decays and channels with missing energy
- Trading loss in statistics with reduction in systematics → perfect tool for SuperB

$|V_{ub}|$

→3 % (excl) 2% (incl)

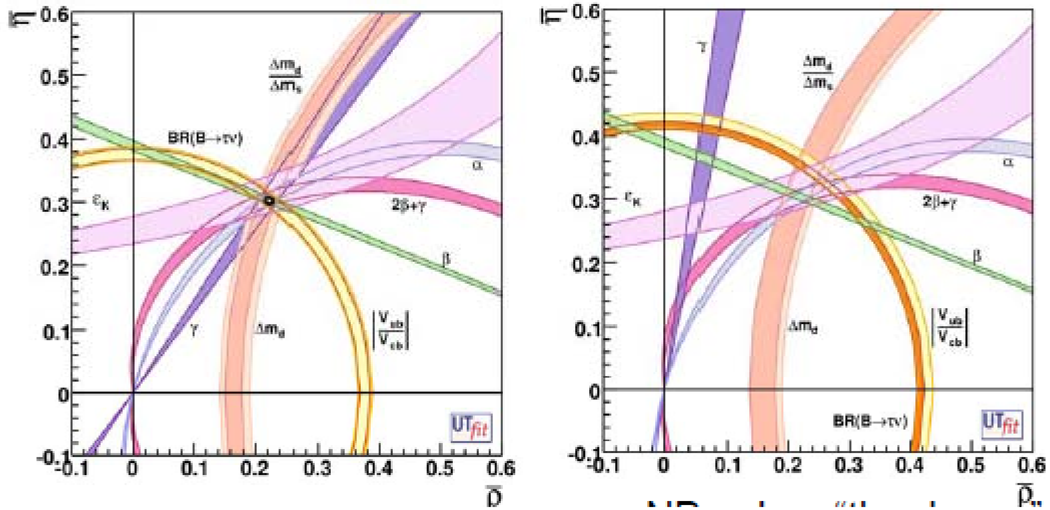
SuperB (75 ab^{-1})

$|V_{cb}|$

precision below the percent level (both excl and incl)

SuperB arXiv:1008.1541

SuperB ($50ab^{-1}$)+lattice improvements



Conclusions

$|V_{cb}|$ Tension with exclusive reduced from 2 σ (PDG 2010) to 1.6 σ (lattice; also uncertainty reduced); even better LCSR

Inclusive computation under improvement (kinetic routine)

$|V_{ub}|$ Exclusive: LCSR (2011) has reached 10% th uncertainty ≈ Lattice FNAL/MILC work in progress to further reduce errors

Still discrepancy with inclusive, despite recent exp progress

Inclusive: approaches needs whatever improvement you can give

Quotation from Altarelli final talk at FPCP 2011 **arXiv:1108.3514**

"I think that this "tension" is due to the fact that over the last 30 years hundreds of theory papers have been devoted to the determination of V_{ub}: each author claiming that his work led to a decrease of the theor. Error"

SuperFlavour's awaited