THE CKM QUARK MIXING MATRIX

A. Ceccucci (CERN), Z. Ligeti (LBL), Y. Sakai (KEK)

Written for the RPP 2006
Regularly updated every two years

Structure:

1. **Introduction**
2. **Magnitudes of CKM elements**
3. **Phases of CKM elements**
4. **Global fit in the Standard Model (SM)**
5. **Implications beyond the SM**

Where are we now

- During the past ten years we have witnessed the success of the CKM picture
- All CP-violation manifestations in lab experiments are amenable to one single complex phase in flavour changing transitions of quarks
- Now Look to deviations from overall consistency of SM
- Updates mainly from new LHC results, Tevatron and B-factories full samples

Updates since the 2010 edition

- Magnitude of CKM elements
  - V_{cs}
    - New measurements of D_s leptonic decays (muons and taus) & f_{Ds} from lattice
    - $|V_{cs}| = 1.008 +/- 0.024$
    - Combined with semi-leptonic:
    - **$|V_{cs}| = 1.006 +/- 0.023$**
  - V_{cb} (follow mini-review)
    - Since the RPP 2008 version, the tension between exclusive and inclusive determinations lead to scaled errors about twice as large as previously quoted
    - Only incremental improvements since RPP 2010
    - **$|V_{cb}| = (40.9 +/- 1.1) \times 10^{-3}$**
  - V_{ub} (follow mini-review)
    - Persistent tension between exclusive and inclusive determinations
    - Average **$|V_{ub}| = (4.15 +/- 0.49) \times 10^{-3}$**
    - A determination (not included in the average) is obtained from $B(B \rightarrow \tau \nu) = (1.67 +/- 0.30) \times 10^{-4}$ and $f_B = 190.6 +/- 4.6$ MeV $|V_{ub}| = (5.10 +/- 0.47) \times 10^{-3}$

Updates since the 2010 edition

- V_{td} & V_{ts} not likely to be precisely determined in tree level processes, rely on neutral meson mixing and K and B rare decays
  - New result from LHCB has reduced the error on Δm_s by about ×3
  - Errors on V_{td} and V_{ts} dominated by lattice QCD inputs
  - Several uncertainties are reduced calculating the ratio $\xi = (f_{Bs} \sqrt{B_{Bs}}) / (f_{Bd} \sqrt{B_{Bd}}) = 1.237 +/- 0.032$ (unquenched)

    $|V_{td} / V_{ts}| = 0.211 +/- 0.001 +/- 0.006$
- V_{tb}: new single top result from CMS
  - Average with D0 and CDF : **$|V_{tb}| = 0.89 +/- 0.07$**

Updates on Phases of CKM elements

- β / ϕ_1 New Belle result (full sampe), average of charmonium modes (Babar+Belle):

  $\sin 2\beta = 0.679 \pm 0.020$

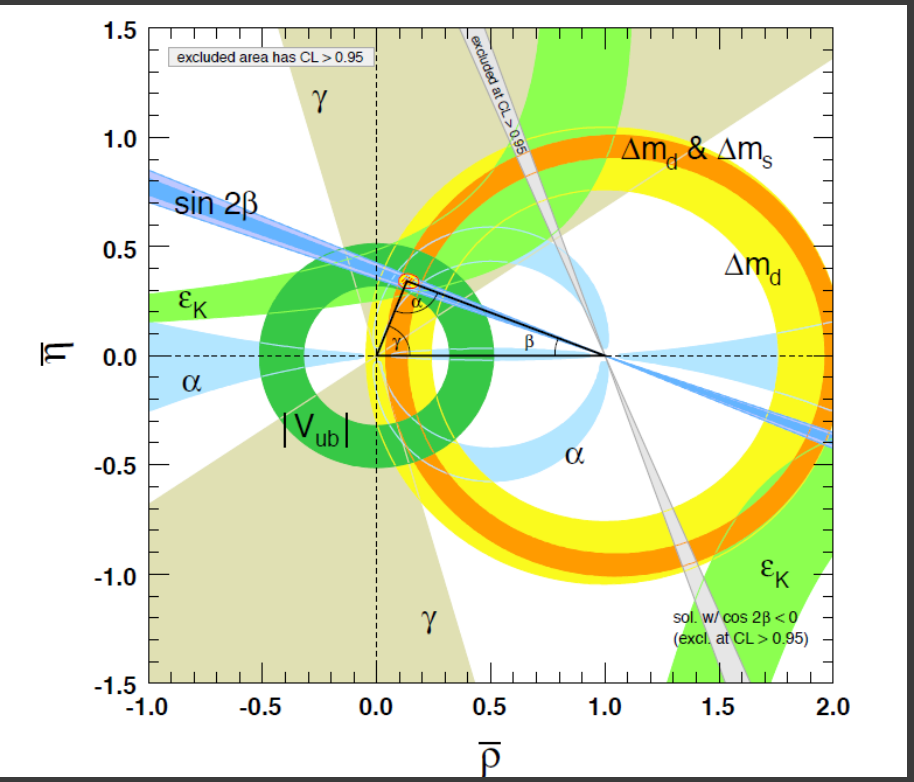
- α / ϕ_2 LHCb first result on $B \to \pi^+\pi^-$
- γ / ϕ_3 new results from CDF, LHCb on $B \to DK$. Combining GLW, ADS and Dalitz methods:

  $\gamma = (68\ ^{+\ 10}_{-11})^\circ$

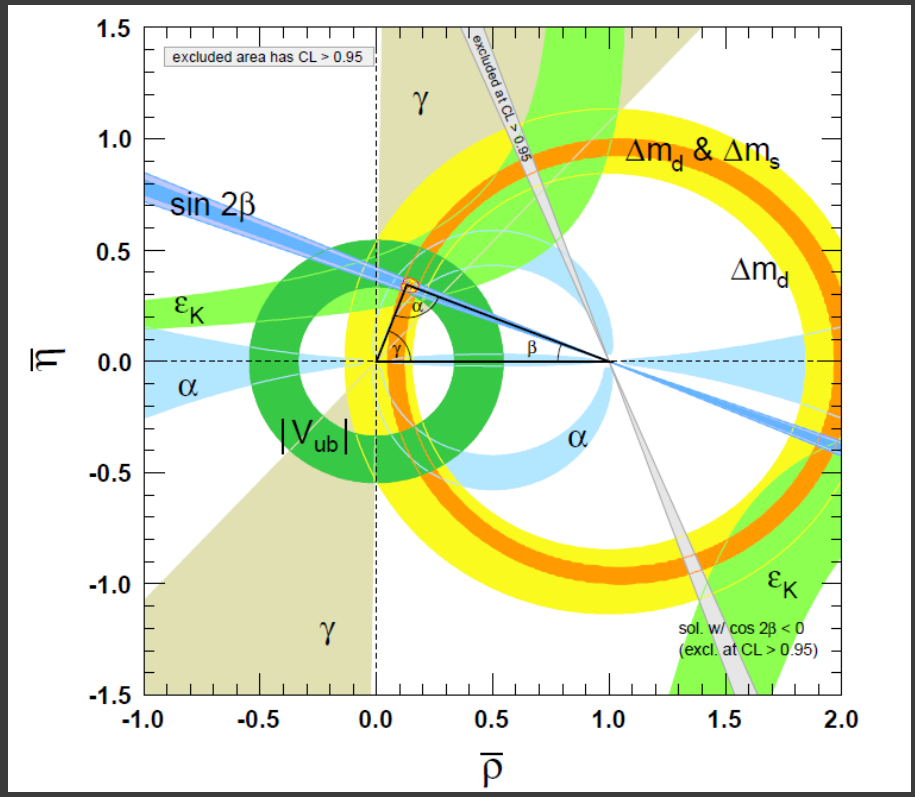
Global Fit to Standard Model

- Using frequentistic prescription (CKMfitter):
  - λ = 0.22535 +/- 0.00065 A= $0.811^{+0.022}_{-0.012}$
  - $\rho = 0.131^{+0.026}_{-0.013}$ $\eta = 0.345^{+0.013}_{-0.014}$
- Using Bayesian prescription (UTfit):
  - λ = 0.22535 +/- 0.00065 A= 0.817+/-0.015
  - ρ = 0.131+/-0.018 η = 0.348+/-0.014

RPP 2010



RPP 2012



Implications Beyond Standard Model

- Many key measurements sensitive to BSM are not useful to in terms of constraining the unitarity triangle
  - For instance, from CP-asymmetries in semileptonic $B^0_{d,s}$ decays, D0 finds a 3.9σ deviation from SM
- A key quantity in the B_s system is $\beta_s = \arg(-V_{ts} V_{tb}^* / V_{cs} V_{cb}^*)$ which is the small λ^2-suppressed angle of a squashed unitarity triangle (scalar product of second and third column)
- $\phi_s = -2\beta_s$
- SM prediction: $\beta_s = 0.018 \pm 0.001$
- LHCb measurement ($1\ fb^{-1}$): **$\beta_s = 0.001 \pm 0.044$**
- Uncertainty is still twice the SM prediction and ~40 times its uncertainties

- Rare kaon decays clean tests of the standard model will be expected from the study of the $K \rightarrow \pi \nu \nu$ bar modes

A few comments

- Several constraints/elements depend significantly on input from theory (decay constants, bag parameters, form factors…)
  - Epsilon
  - Δm_d
  - Δm_s
  - 2+1 Flavor Lattice QCD averages
- Average and error treatment of theory input not always straightforward
  - $f_+(0), f_{K,D,B}$
  - B, quark masses,…
- Persistent tension on the determination of V_{ub}
  - $B \rightarrow \tau \nu$??