Global Fits of the Unitarity Triangle and Searches for New Physics in Pseudoscalar Pseudoscalar Final States

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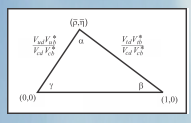
Abstract

We present the results of a unitary triangle fit based on the scan method. This frequentist approach uses Gaussian errors for experimental quantities, but makes no arbitrary assumptions about the distribution of theoretical errors. Instead, we perform a large number of fits, scanning over regions of plausible theory errors for each quantity, and retain those fits meeting a specific confidence level criterion, thereby constraining the $\bar{\rho}$ -$\bar{\eta}$ plane using the standard input measurements (CKM matrix elements, sin2β, $B^0_{d,s}$ mixing, ε_K) as well as branching fraction and *CP* asymmetry measurements of B decays to all light $B\to PP$, PV, VV, and a_1P decay modes to determine α, $D^{(*)}K^{(*)}$ modes to determine γ, and $D^{(*)}\pi$ and $D\rho$ modes to determine $2\beta+\gamma$. We parameterize individual decay amplitudes in terms of color-allowed tree, color-suppressed tree, penguin, singlet penguin, electroweak penguin, as well as the W-exchange and W-annihilation amplitudes. With this parameterization, we obtain a good fit to the measured branching fractions and *CP* asymmetries of all B decays to PP mesons without any New Physics contributions. This simultaneous fit allows us to determine the correlation between α and β.

Introduction

- The phase of the CKM matrix produces *CP* violation in the Standard Model (SM)
- Unitarity relations of the CKM matrix provide an excellent laboratory to test this prediction
- The relation $V^*_{ub}V_{ud}+V^*_{cb}V_{cd}+V^*_{tb}V_{td}=0$ is particularly useful, since many measurements in the B and K systems can be combined for the test



Fit Methodology

- The scan method is a frequentist-based technique for fitting elements of the CKM matrix
- Theory uncertainties in the QCD parameters f_{Bs}, f_{bs}/f_{bd}, B_{Bs}, B_{bs}/B_{Bd}, and B_K and the CKM parameters V_{ub} and V_{cb} are accounted for by scanning over the range in the theory uncertainty using a grid or MC methods
- In the standard fit, we combine measurements of Δm_d, Δm_s, ε_K, V_{cb}, V_{ub}, V_{us}, V_{ud}, sin2β, α, and γ in the χ^2
- We constrain the mean values of the QCD parameters to their predicted values with Gaussian functions in which the width is fixed to the "statistical" uncertainty obtained from the lattice ➔yields terms ($\mathcal{T}_n$) in the χ^2
- To account for correlations in observables we add measurements for quark masses, B meson masses and lifetimes ➔yields terms ($\mathcal{M}_k$)

$$\chi^2(\vec{p},\bar\eta;p_i,t_j) = \left(\frac{\langle\Delta m_{B_d}\rangle - \Delta m_{B_d}(\vec{p},\bar\eta;p_i,t_m)}{\sigma_{\Delta m_{B_d}}}\right)^2 + \left(\frac{\langle|V_{cb,ub,ud,us}|\rangle - V_{cb,ub,ud,us}(\vec{p},\bar\eta;p_i,t_m)}{\sigma_{V_{cb,ub,ud,us}}}\right)^2$$
$$+\left(\frac{|\varepsilon_K| - |\varepsilon_K|(A,\bar\rho,\bar\eta;p_i,t_m)}{\sigma_{\varepsilon_K}}\right)^2 + \left(\frac{\langle\alpha_{\beta\gamma}\rangle - \sin2\beta(\bar\rho,\bar\eta;p_i)}{\sigma_{\sin2\beta}}\right)^2 + \sum_k\left(\frac{\langle\mathcal{M}_k\rangle - \mathcal{M}_k(p_i)}{\sigma_{\mathcal{M}_k}}\right)^2$$
$$+\sum_n\left(\frac{\langle\mathcal{T}_n\rangle - \mathcal{T}_n(p_i,t_m)}{\sigma_{\mathcal{T}_n}}\right)^2 + \left(\frac{\langle\alpha\rangle - \alpha(\bar\rho,\bar\eta;p_i)}{\sigma_\alpha}\right)^2 + \left(\frac{\langle\gamma\rangle - \gamma(\bar\rho,\bar\eta;p_i)}{\sigma_\gamma}\right)^2$$

p_i are parameters (A, λ, ...), t_m are QCD parameters

- For each choice of a set of theory parameters we determine the χ^2
- For fits with P(χ^2)>5%, we plot $\bar\rho$-$\bar\eta$ contours and study correlations among the theory parameters
- The contours of all accepted fits are overlaid

Inputs to the Standard Fits

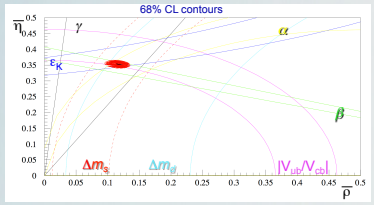
Observable	Value
m_t	174.65±0.11 Gev/c^2
m_t [PDG12]	173.5±0.9 Gev/c^2
m_c	1.29±0.11 Gev/c^2
m_c [PDG12]	1.275±0.025 Gev/c^2
Δm_d	0.507±0.004 ps^{-1}
Δm_s	17.70±0.08 ps^{-1}
ε_K	(2.228±0.0011)*10^{-3}
V_{cb}	(4.06±0.13)*10^{-2}
V_{cb} [PDG12]	(4.09±0.026±0.11)*10^{-2}
V_{ub}	(3.89±0.44)*10^{-3}
V_{ub} [PDG12]	(4.15±0.1±0.48)*10^{-3}
V_{us}	0.2254±0.0009
V_{ud}	0.97427±0.00021
sin2β	0.676±0.02
α	90±5
γ	76±10

Observable	Value
f_{Bs}	250±5.4±11 MeV
f_{Bs}/f_{Bd}	1.215±0.012±0.015
B_{Bs}	1.33±0.06
B_{Bs}/B_{Bd}	1.05±0.07
B_K	0.737±0.006±0.020
η_{cc}	1.39±0.35
η_{tc}	0.5765±0.0065
η_{tt}	0.47±0.04
η_b	0.551±0.007

The η_{xy} parameters are here not scanned
η_{cc} and its uncertainty are parameterized in terms of m_c and α_s

Comparison with CKMfitter & UTfit

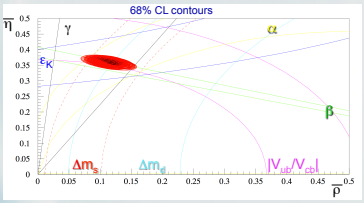
- First, we test the performance wrt CKMfitter and Utfit fitting 19 measurements (V_{ud}, V_{us}, V_{cb}, V_{ub}, ε_K, Δm_d, Δm_s, sin 2β, α, γ, f_{Bs}, B_{Bs}, f_{Bs}/f_{Bd}, B_{Bs}/B_{Bd}, B_K, m_t, m_c, t_{Bd}, t_{Bs}) with 13 parameters (ρ, η, A, λ, f_{Bs}, B_{Bs}, f_{Bs}/f_{Bd}, B_{Bs}/B_{Bd}, B_K, m_t, m_c, t_{Bd}, t_{Bs})
- For fits with P(χ^2)>32%, we plot 1σ contours in the $\bar\rho$-$\bar\eta$ plane



- All 3 methods yield similar results, but there is no scanning over V_{ub}, V_{cb}, B_{Bs}, and B_{Bs}/B_{Bd}

Parameter	Scan method	Scan m. (V_{ub}/V_{cb})	CKMfitter	UTfit
ρ	0.121+0.015-0.025	0.132+0.027-0.06	0.121±0.02	0.125±0.022
η	0.351+0.015-0.012	0.359+0.025-0.025	0.349±0.012	0.347±0.014
β[°]	21.8+0.6-0.7	22.5+0.4-1.3	21.7±1	21.6±0.8
α[°]	87.2+2.3-4.0	87.7+9.2-5.3	87.5±3.2	87.9±3.4
γ[°]	71.0+4.1-2.2	69.8+9.8-4.6	70.9±3.2	70.4±3.4

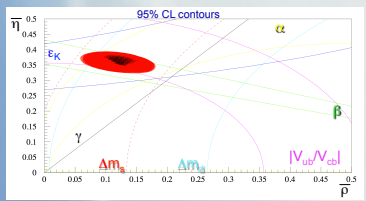
- We perform a fit with the new PDG12 V_{ub} and V_{cb} averages that use scaling factors of 2.6 and 2.0 for averaging inclusive and exclusive modes, respectively
- We scan over the theory uncertainties determined from the PDG total uncertainties subtracting statistical errors in quadrature that we determine from our own averaging (arXiv:0806.0530)



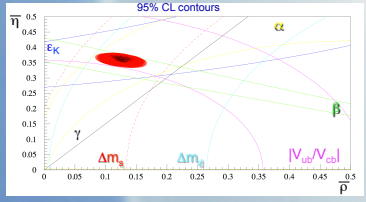
- The scan over V_{ub} and V_{cb} increases the allowed $\bar\rho$-$\bar\eta$ region up to a factor of two

Global Fits of the CKM matrix

- Fit with standard 19 measurements



- Fits that also include $B^\pm\to\tau^\pm\nu$



Results with and without $B\to\tau\nu$

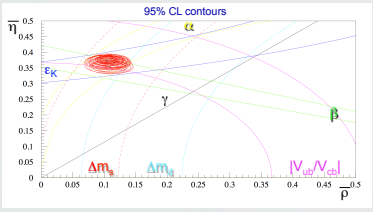
- $B\to\tau\nu$ reduces allowed region in the $\bar\rho$-$\bar\eta$ plane

Parameter	Scan-fit w/o $B\to\tau\nu$	Scan-fit w $B\to\tau\nu$
ρ	0.058—0.181	0.085—0.159
η	0.324—0.394	0.334—0.377
β[°]	20.8—23.7	21.2—22.9
α[°]	77.1—95.9	76.9—92.9
γ[°]	62.3—81.0	65.2—76.9

(95% CL contours)

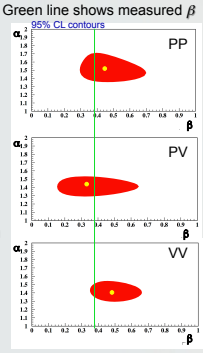
Extended CKM Fits

- We also perform fits in which we add many more measurements that replace the direct input variables α and γ (230 meas., 104 fit param.)
- This procedure accounts for possible correlations between α and β or γ and β
- Presently, we include
  - all $\mathcal{B}$ and $\mathcal{A}_{CP}$ measurements of $B\to PP$, $B\to PV$, and $B\to VV$ modes ➔ determine α ($B\to Pa_1$ is not yet included)
  - amplitude ratios and $\mathcal{A}_{CP}$ measurements of $B^\pm\to DK^\pm$, $B^\pm\to D^*K^\pm$, and $B\to DK^{*\pm}$ modes ➔ determine γ
  - amplitude ratios and $\mathcal{A}_{CP}$ measurements of $B^\pm\to D\pi^\pm$, $B^\pm\to D^*\pi^\pm$, and $B\to D\rho^\pm$ modes ➔ determine sin(2β+γ)
- We include tree, color-suppressed tree, penguin, singlet penguin, W-exchange, W-annihilation, and EW penguin amplitudes (up to λ^2 beyond LO)



- We fit the $B\to PP$, $B\to PV$ and $B\to VV$ modes separately to plot α-β contours at 95% CL

Green line shows measured β



- Contours are rather wide and consistent with measured WA β=0.374±0.014 from sin 2β $c\bar{c}s$ modes

Mode	α [±1σ]	β [+1σ -1σ]
$B\to PP$	1.51±0.06	0.45+0.07-0.06
$B\to PV$	1.41±0.07	0.32+0.06-0.05
$B\to VV$	1.42±0.09	0.48+0.13-0.10

Conclusions

- For inputs with no theory errors on V_{ub} and V_{cb} the results of the scan method, CKMfitter and UTfit are compatible
- Scanning over the theory errors in V_{ub} and V_{cb} is vital, as the allowed region in the ρ-η plane increases significantly
- Inclusion of $\mathcal{B}(B^\pm\to\tau^\pm\nu)$ reduces, but does not eliminate, the allowed region in the $\bar\rho$-$\bar\eta$ plane
- In the fit of $B\to PP$, $B\to PV$, and $B\to VV$ modes, correlations in the α-β contours are small ➔ largest correlation is seen in $B\to PP$