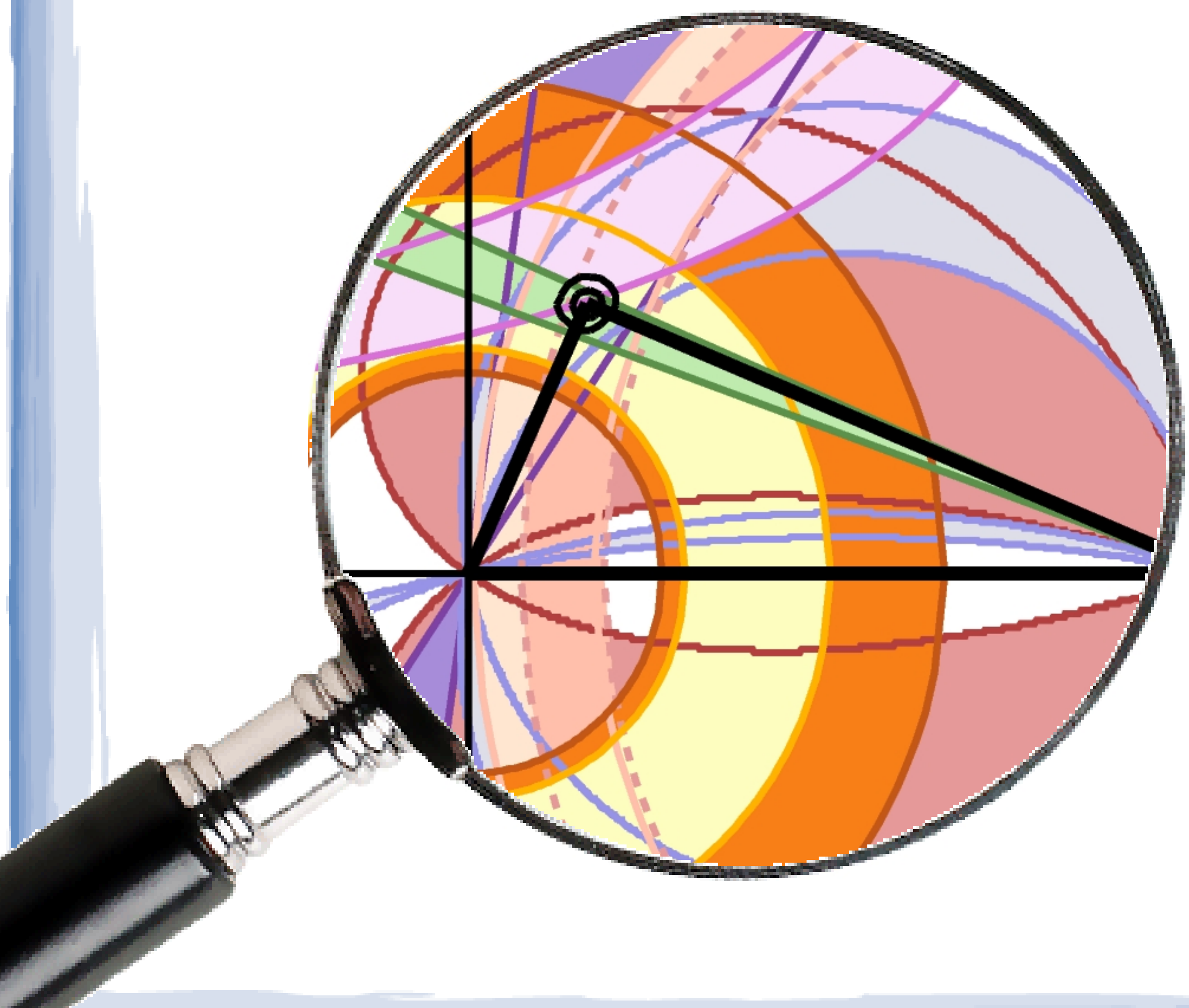
Updates from UTfit within and beyond the Standard Model



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UK Flavour Workshop
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Durham, UK

unitarity Triangle analysis in the SM

- SM UT analysis:
  - provide the best determination of CKM parameters
  - test the consistency of the SM ("*direct*" vs "*indirect*" determinations)
  - provide predictions for SM observables (ex. $\sin 2\beta$, Δm_s, ...)

.. and beyond

- NP UT analysis:
  - model-independent analysis
  - provides limit on the allowed deviations from the SM
  - updated NP scale analysis

CKM matrix and Unitarity Triangle

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

many observables functions of $\bar{\rho}$ and $\bar{\eta}$: overconstraining

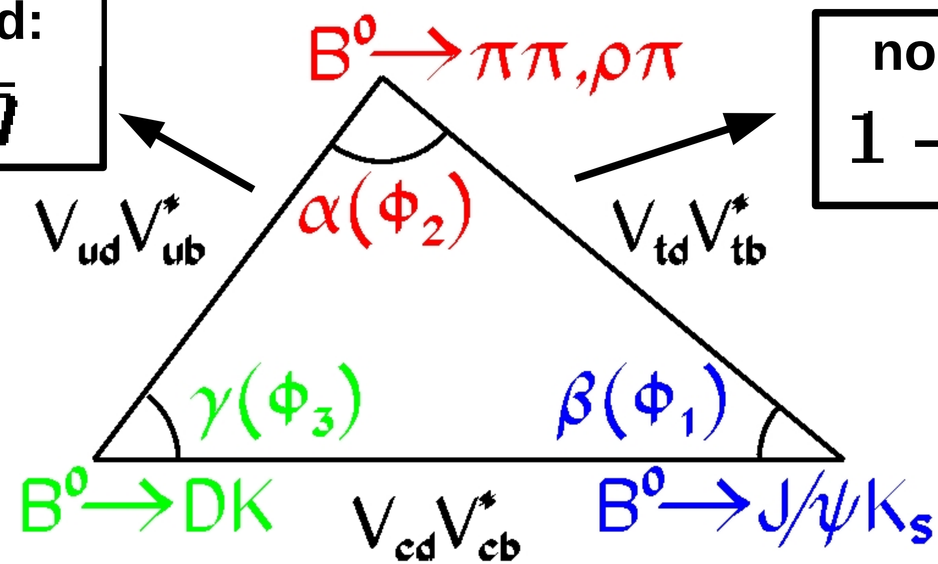
$$\alpha = \pi - \beta - \gamma$$

normalized:

$$\bar{\rho} + i\bar{\eta}$$

normalized:

$$1 - \bar{\rho} - i\bar{\eta}$$



$$\gamma = atan\left(\frac{\bar{\eta}}{\bar{\rho}}\right)$$

$$\beta = atan\left(\frac{\bar{\eta}}{(1-\bar{\rho})}\right)$$

www.utfit.org

A. Bevan, M.B., M. Ciuchini, D. Derkach,
E. Franco, V. Lubicz, G. Martinelli, F. Parodi,
M. Pierini, C. Schiavi, L. Silvestrini, A. Stocchi,
V. Sordini, C. Tarantino and V. Vagnoni

Other UT analyses exist, by:

CKMfitter (http://ckmfitter.in2p3.fr/),
Laiho&Lunghi&Van de Water (http://krone.physik.unizh.ch/~lunghi/webpage/LatAves/page3/page3.htm),
Lunghi&Soni (1010.6069)

the method and the inputs:

$$f(\bar\rho,\bar\eta,X|c_1,...,c_m) \sim \prod_{j=1,m} f_j(\mathcal{C}|\bar\rho,\bar\eta,X) * \prod_{i=1,N} f_i(x_i) f_0(\bar\rho,\bar\eta)$$

Bayes Theorem

$$X \equiv x_1,...,x_n = m_t, B_K, F_B, ...$$

$$\mathcal{C} \equiv c_1,...,c_m = \epsilon, \Delta m_d/\Delta m_s, A_{CP}(J/\psi K_S), ...$$

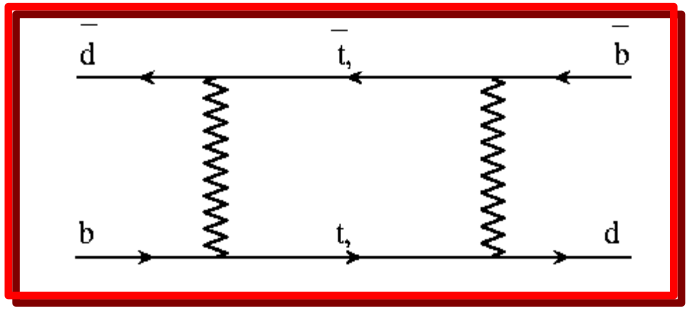
$(b\to u)/(b\to c)$	$\bar\rho^2+\bar\eta^2$	$\bar\Lambda, \lambda_1, F(1), ...$
ϵ_K	$\bar\eta[(1-\bar\rho)+P]$	B_K }
Δm_d	$(1-\bar\rho)^2+\bar\eta^2$	$f_B^2 B_B$
$\Delta m_d/\Delta m_s$	$(1-\bar\rho)^2+\bar\eta^2$	ξ
$A_{CP}(J/\psi K_S)$	$\sin 2\beta$	

, **mt**

Standard Model + OPE/HQET/ Lattice QCD to go from quarks to hadrons

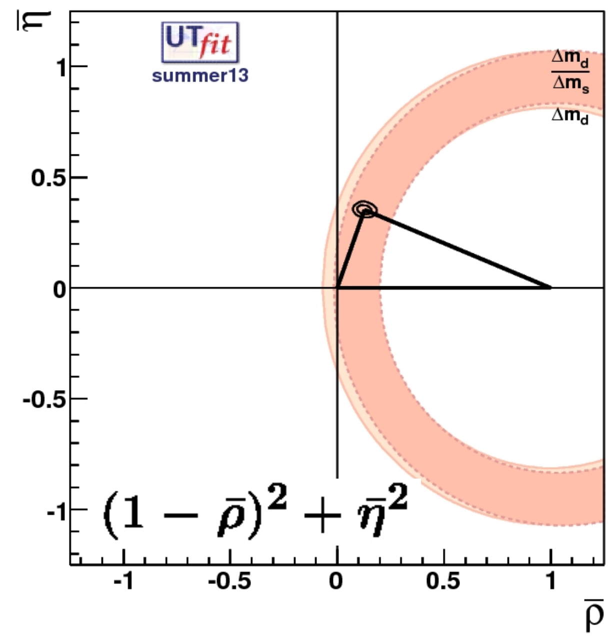
M. Bona *et al*. (UTfit Collaboration) JHEP 0507:028,2005 hep-ph/0501199
M. Bona *et al*. (UTfit Collaboration) JHEP 0603:080,2006 hep-ph/0509219

B_d and B_s mixing



Δm_d=(0.510 ± 0.004) ps^{-1}

Δm_s=(17.72 ± 0.04) ps^{-1}



$\Delta m_s / \Delta m_d$

Δm_d

$$\Delta m_d \approx [(1-\rho)^2+\eta^2]\frac{f_{B_s}^2 B_{B_s}}{\xi^2}$$

$$\Delta m_s \approx f_{B_s}^2 B_{B_s}$$

B_{B_q} and f_{B_q} from lattice QCD

B_K	0.766 ± 0.010
f_{B_s}	0.2277 ± 0.0045
f_{B_s}/f_{B_d}	1.202 ± 0.022
$\hat{B}_{B_s}$	1.33 ± 0.06
$\hat{B}_{B_s}/\hat{B}_{B_d}$	1.06 ± 0.11

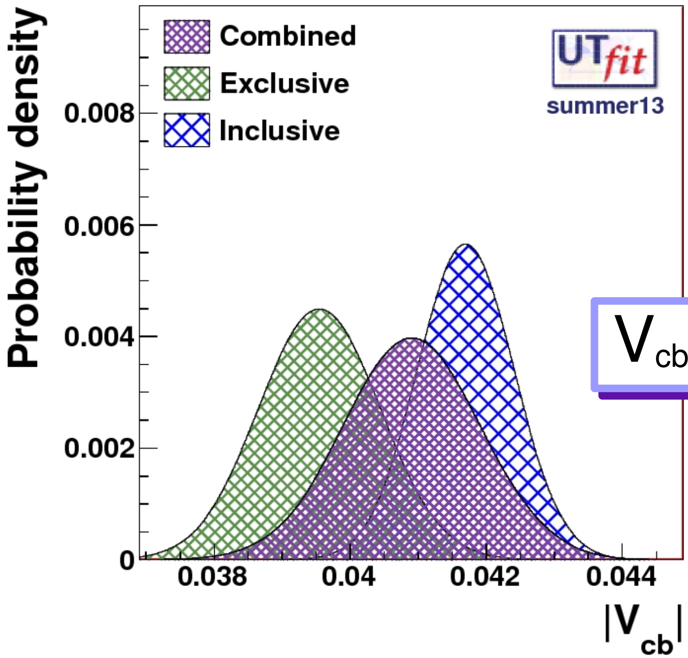
updated results from FLAG-2

V_{cb} and V_{ub}

V_{cb} *(excl)* = (39.55 ± 0.88) 10^{-3}

V_{cb} *(incl)* = (41.7 ± 0.7) 10^{-3}

~1.9σ discrepancy



UTfit input value: average à la PDG

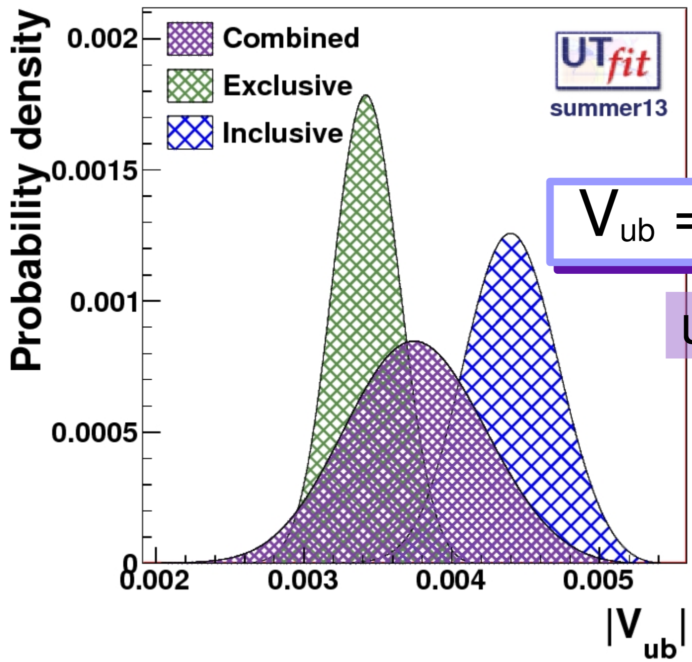
V_{cb} = (40.9 ± 1.0) 10^{-3}

uncertainty ~ 2.4%

V_{ub} *(excl)* = (3.42 ± 0.22) 10^{-3}

V_{ub} *(incl)* = (4.40 ± 0.31) 10^{-3}

~2.5σ discrepancy

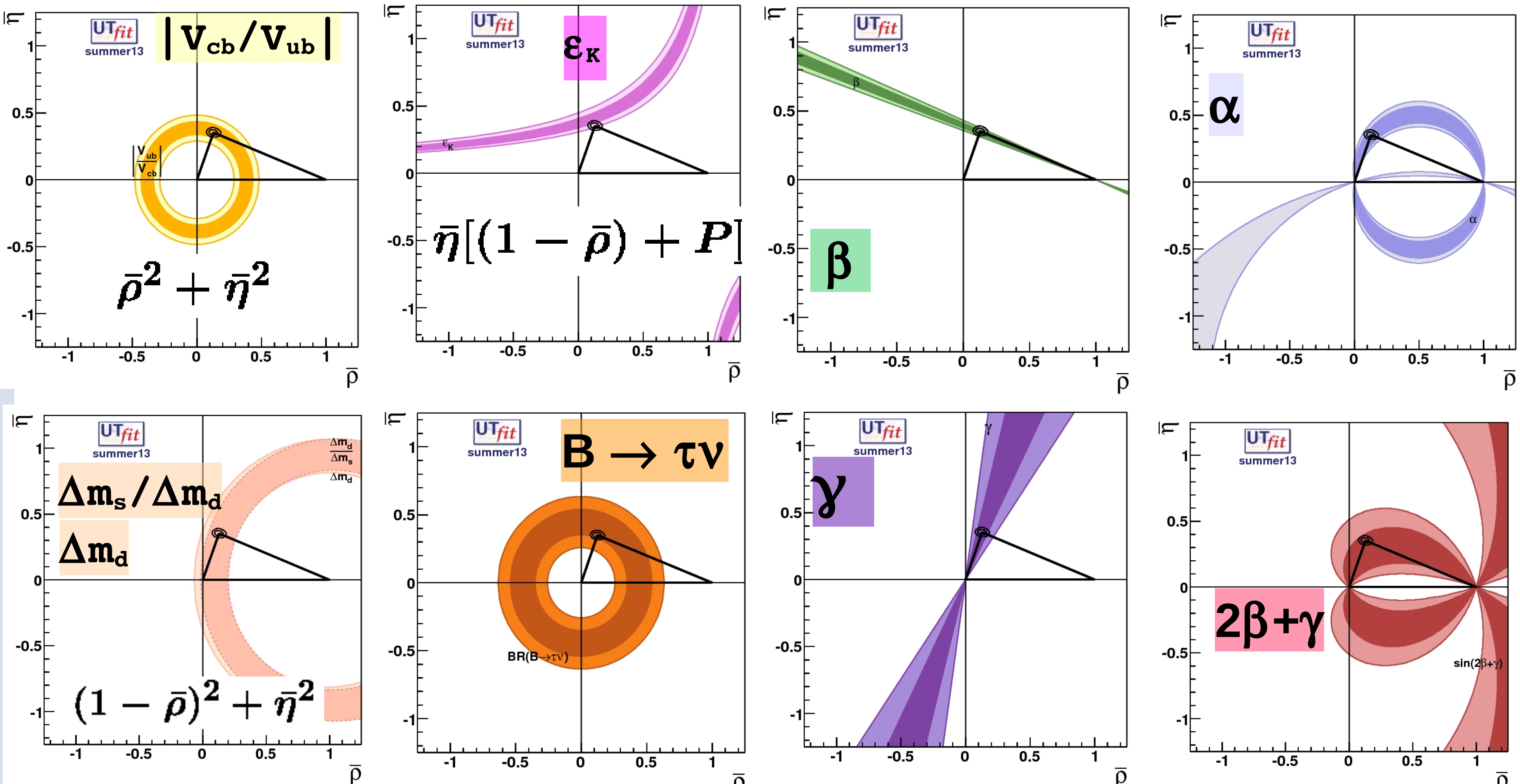


UTfit input value: average à la PDG

V_{ub} = (3.75 ± 0.46) 10^{-3}

uncertainty ~ 12%

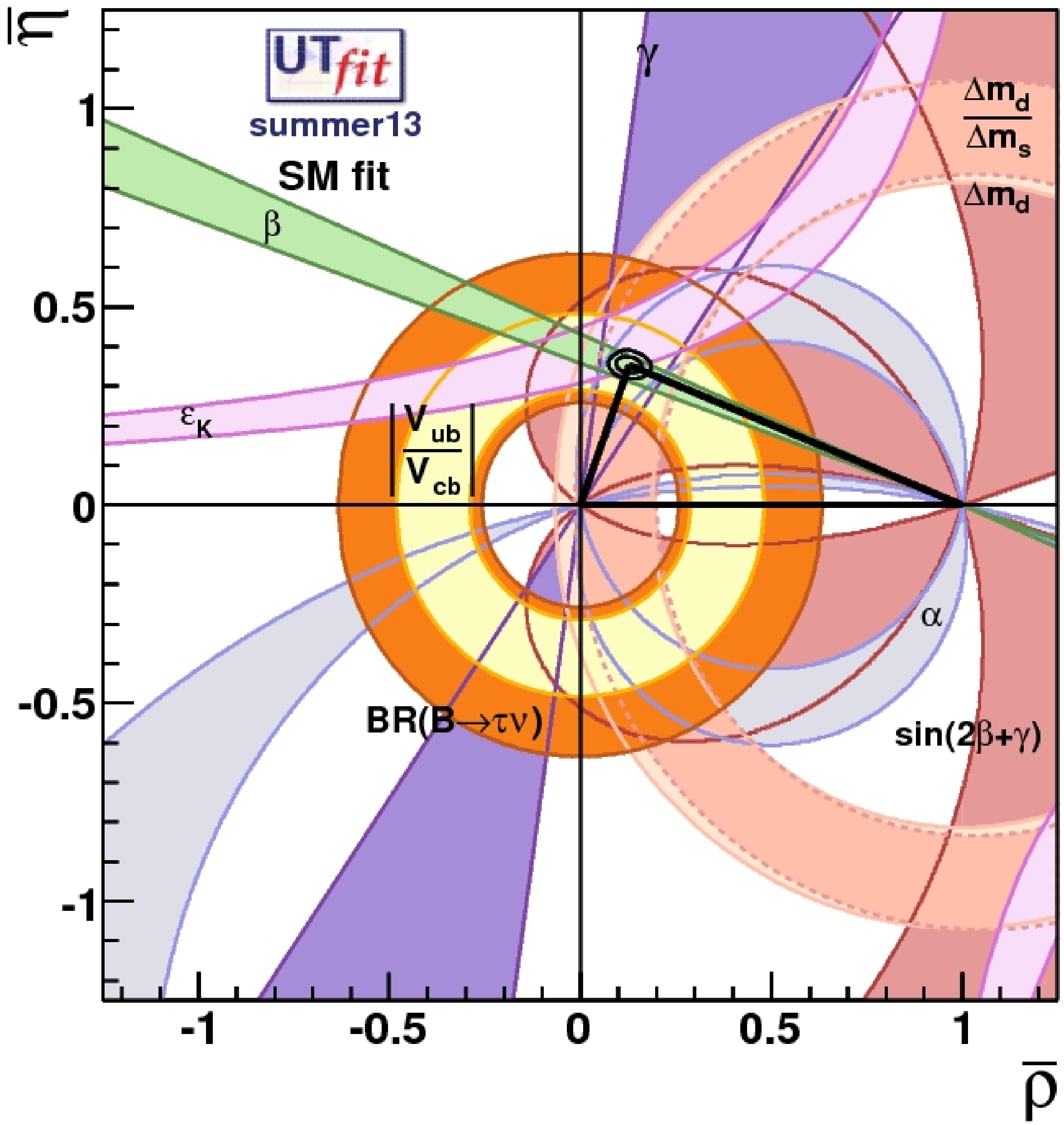
Unitarity Triangle analysis in the SM:



Unitarity Triangle analysis in the SM:

Observables	Accuracy
$\lvert V_{ub}/V_{cb}\rvert$	~ 13%
ε_K	~ 0.5%
Δm_d	~ 1%
$\lvert\Delta m_d/\Delta m_s\rvert$	~ 1%
$\sin 2\beta$	~ 3%
α	~ 8%
γ	~ 10%
$BR(B \to \tau\nu)$	~ 19%

Unitarity Triangle analysis in the SM:



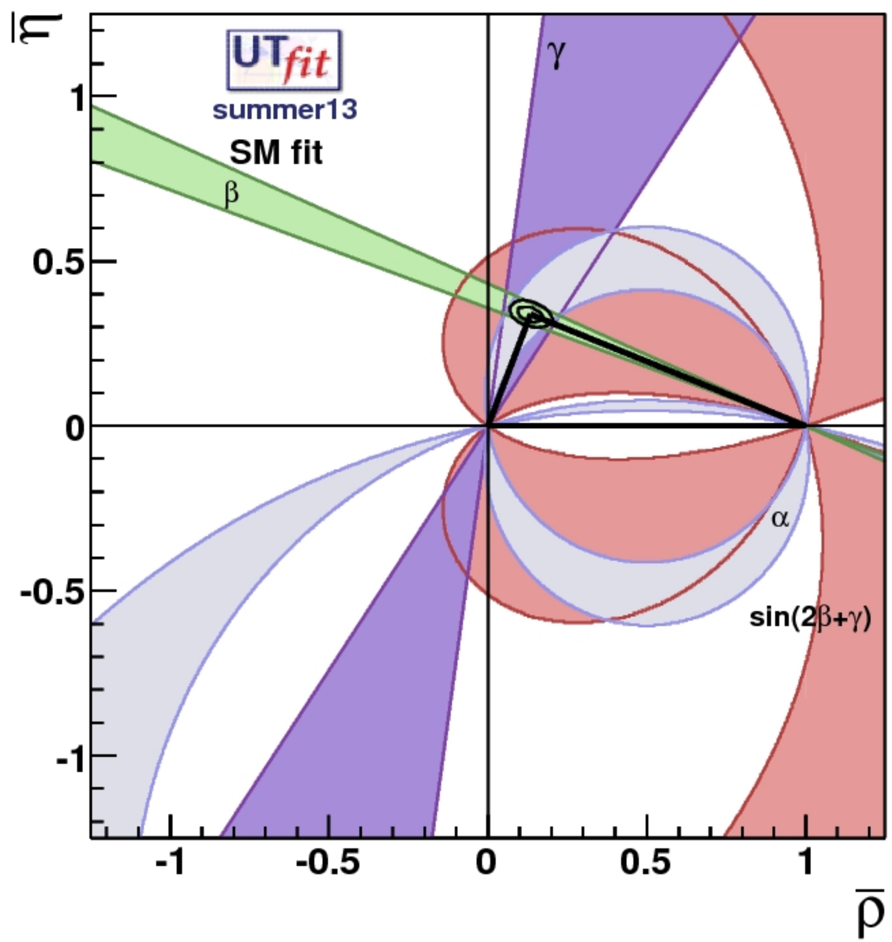
levels @
95% Prob

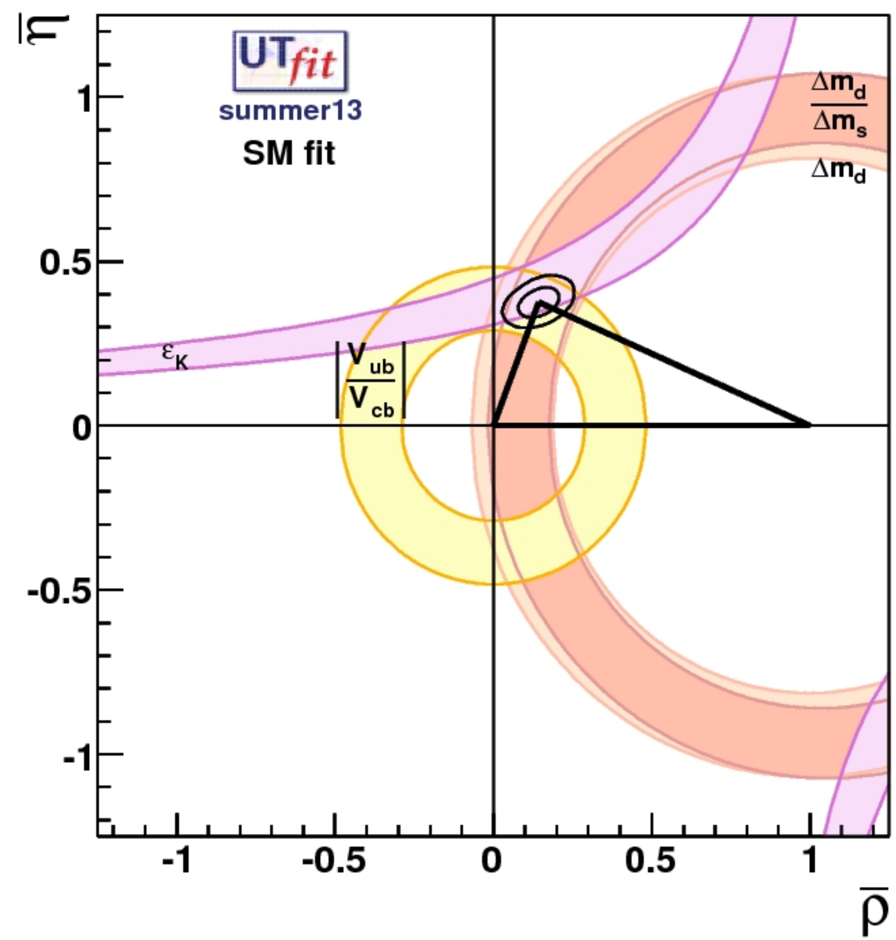
$\bar{\rho} = 0.129 \pm 0.024$

$\bar{\eta} = 0.353 \pm 0.016$

angles vs the others

levels @
95% Prob





$\bar{\rho} = 0.134 \pm 0.029$
$\bar{\eta} = 0.339 \pm 0.017$

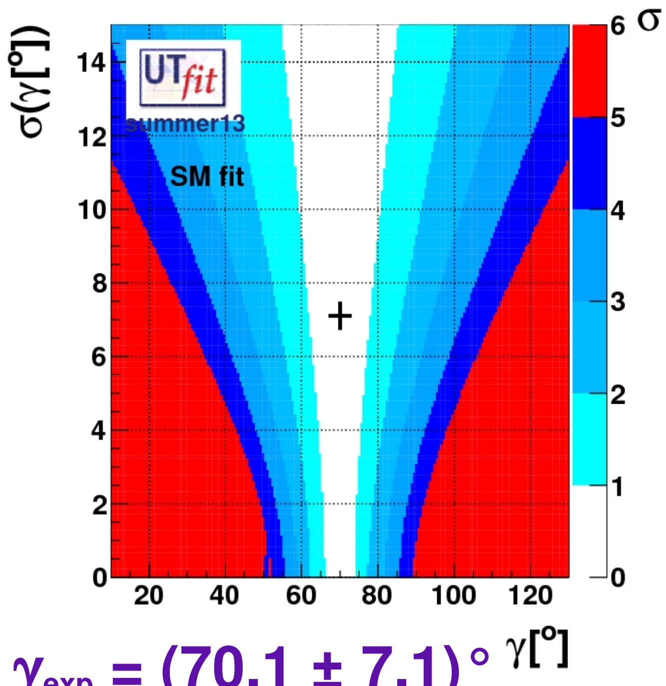
$\bar{\rho} = 0.144 \pm 0.046$
$\bar{\eta} = 0.376 \pm 0.030$

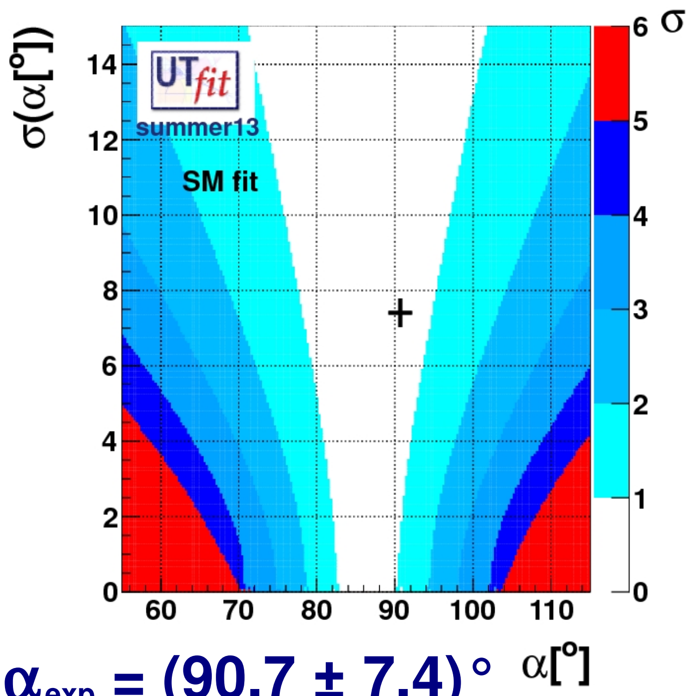
compatibility plots

A way to "measure" the agreement of a single measurement with the indirect determination from the fit using all the other inputs: test for the SM description of the flavour physics

Color code: agreement between the predicted values and the measurements at better than 1, 2, ...nσ

The cross has the coordinates (x,y)=(central value, error) of the direct measurement





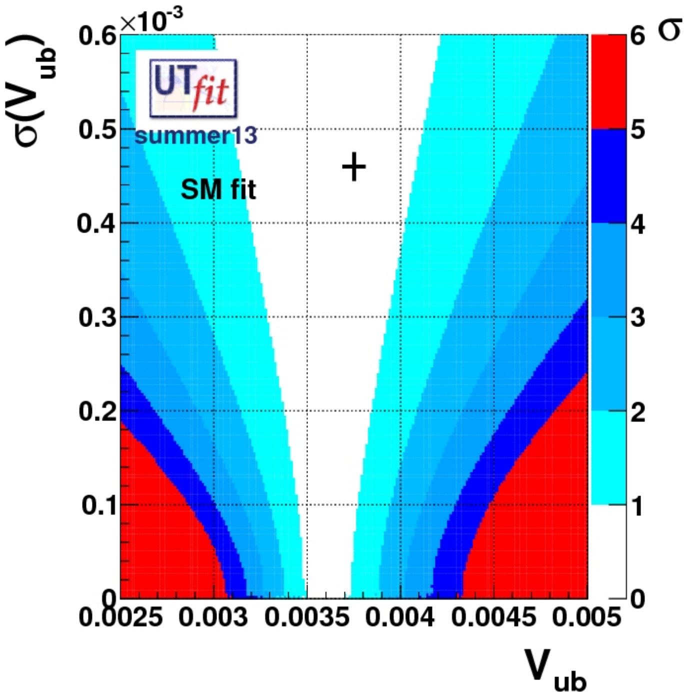
$\gamma_{exp} = (70.1 \pm 7.1)^\circ$

$\gamma_{UTfit} = (69.8 \pm 3.9)^\circ$

$\alpha_{exp} = (90.7 \pm 7.4)^\circ$

$\alpha_{UTfit} = (86.4 \pm 3.9)^\circ$

tensions



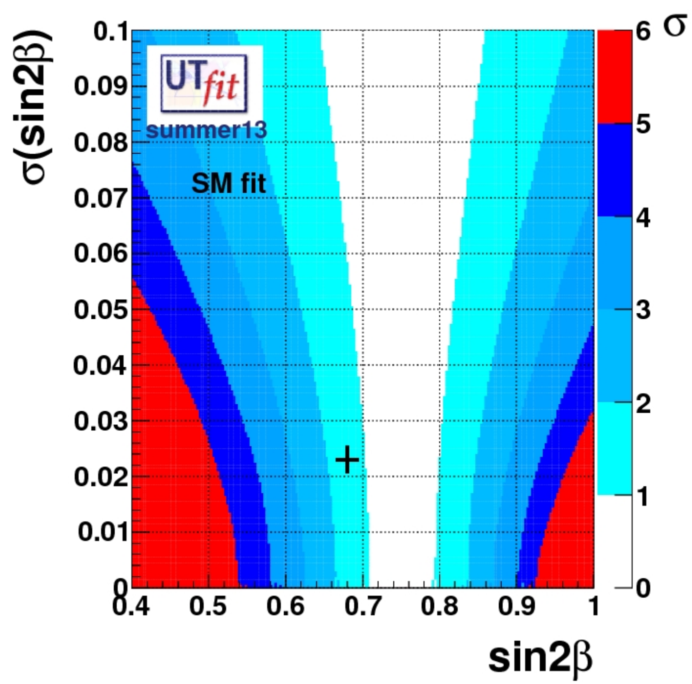
$Vub_{exp} = (3.75 \pm 0.46) \cdot 10^{-3}$

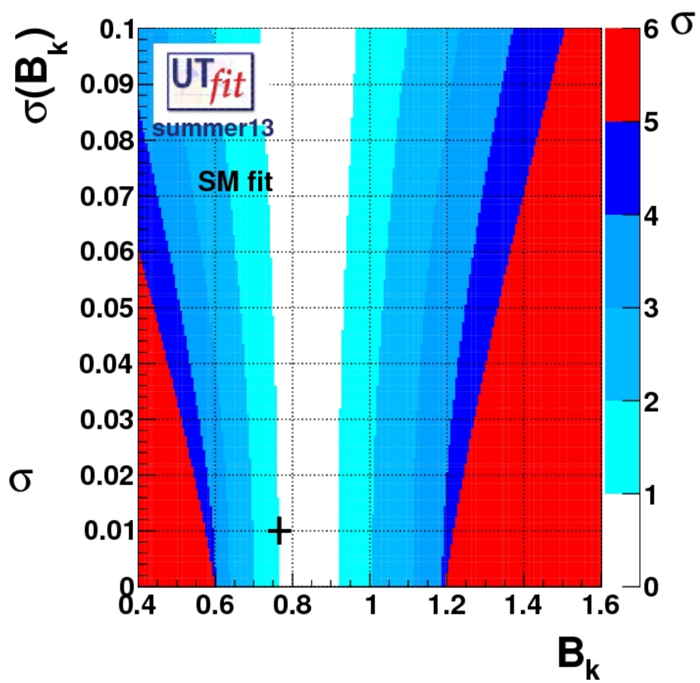
$Vub_{UTfit} = (3.62 \pm 0.13) \cdot 10^{-3}$

~1.5σ

$\sin 2\beta_{exp} = 0.680 \pm 0.023$

$\sin 2\beta_{UTfit} = 0.752 \pm 0.043$



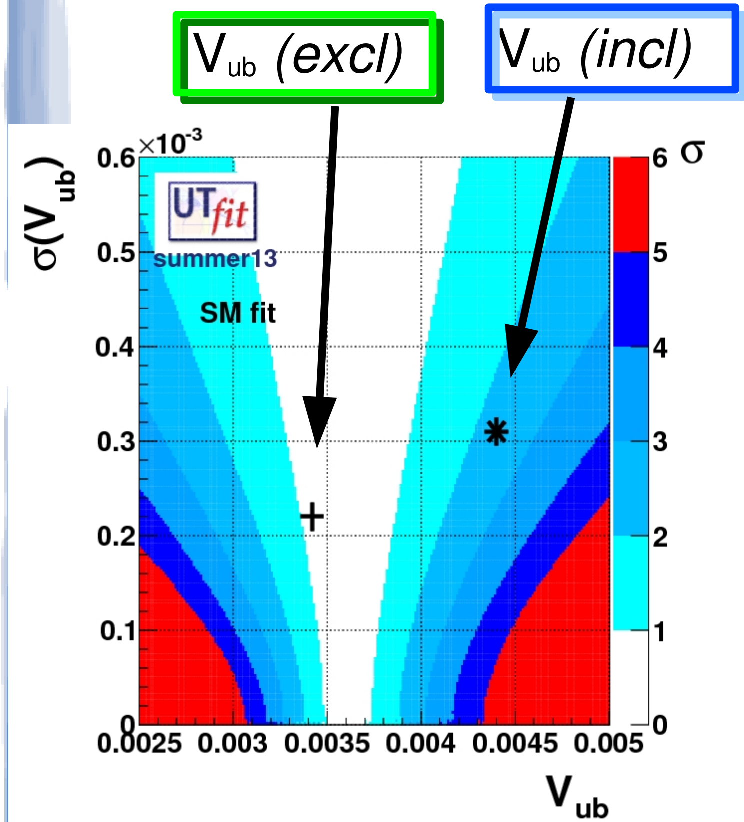


$B_{Kexp} = 0.766 \pm 0.010$

$B_{KUTfit} = 0.841 \pm 0.078$

<1σ

tensions



$Vub_{exp} = (3.75 \pm 0.46) \cdot 10^{-3}$

$Vub_{UTfit} = (3.62 \pm 0.13) \cdot 10^{-3}$

~1.5σ

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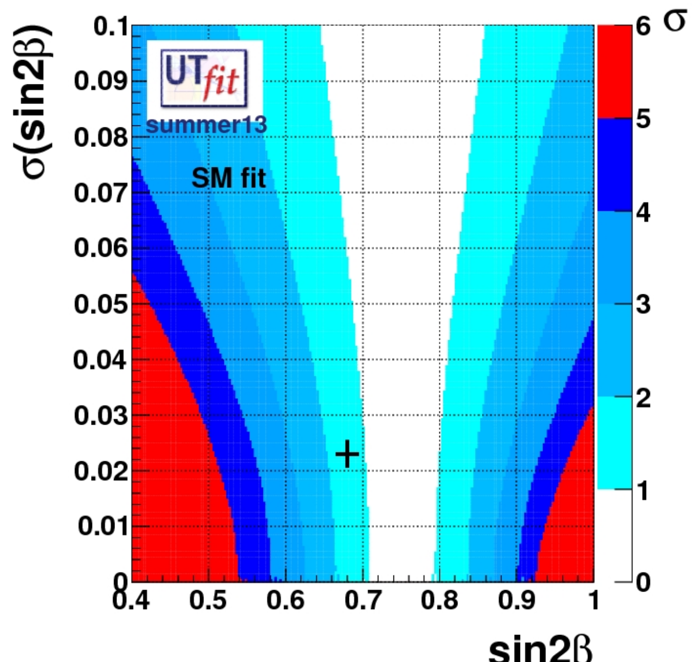
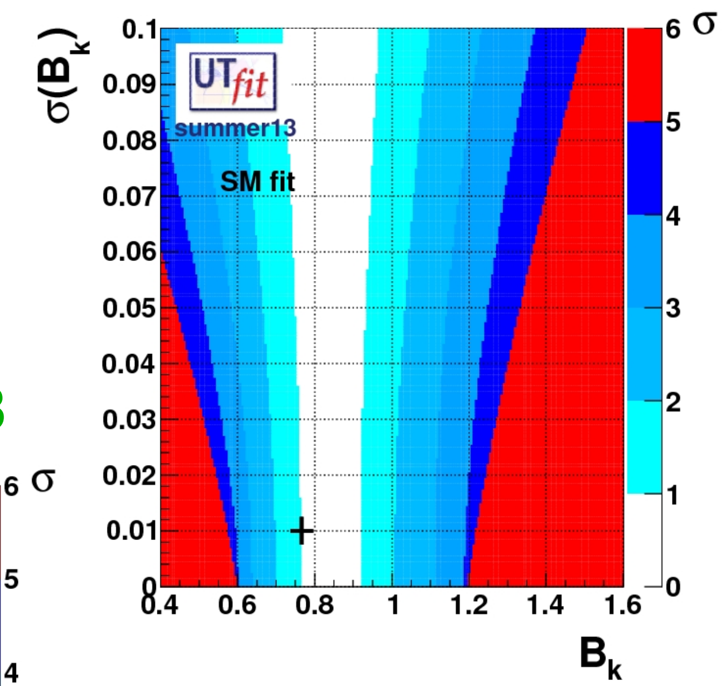




$B_{Kexp} = 0.766 \pm 0.010$

$B_{KUTfit} = 0.841 \pm 0.078$

<1σ

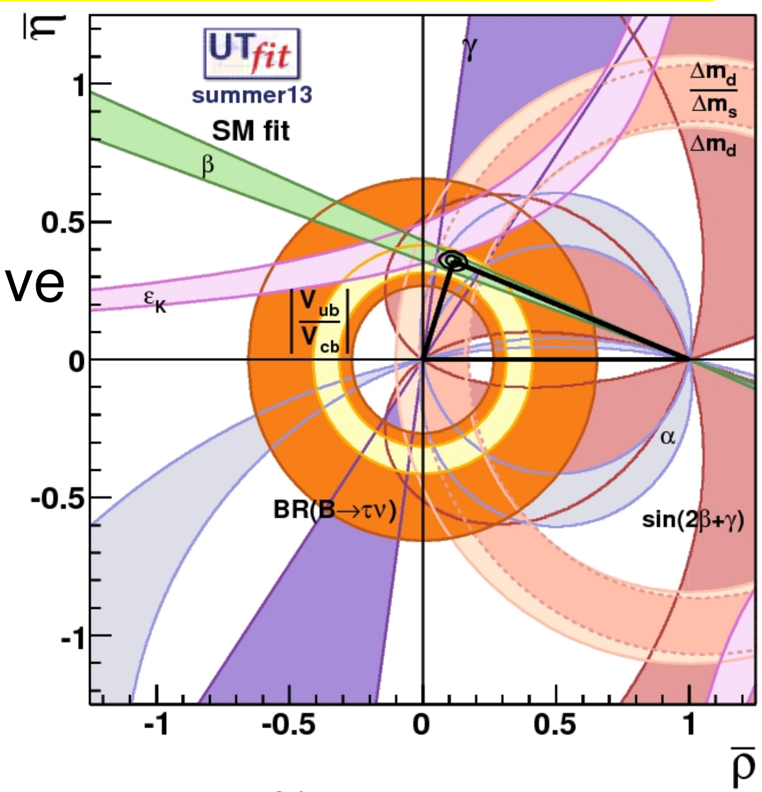
Unitarity Triangle analysis in the SM:

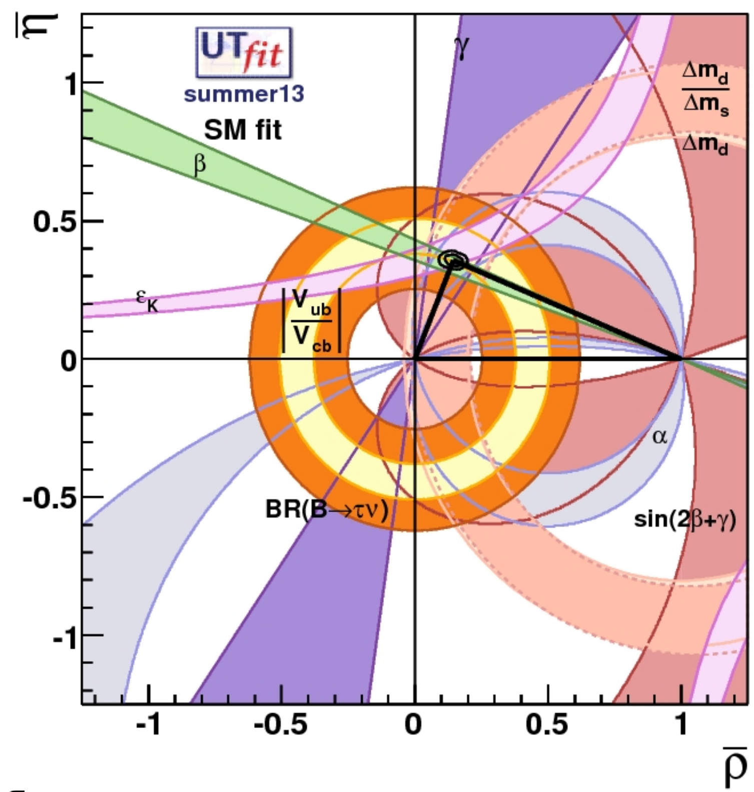
obtained excluding the given constraint from the fit

Observables	Measurement	Prediction	Pull (#σ)
$\sin 2\beta$	0.680 ± 0.023	0.752 ± 0.043	~ 1.5
γ	70.1 ± 7.1	69.8 ± 3.9	< 1
α	90.7 ± 7.4	86.4 ± 3.9	< 1
$\lvert V_{ub}\rvert \cdot 10^3$	3.75 ± 0.46	3.62 ± 0.13	< 1
$\lvert V_{ub}\rvert \cdot 10^3$ (incl)	4.40 ± 0.31	–	~ 2.3
$\lvert V_{ub}\rvert \cdot 10^3$ (excl)	3.42 ± 0.22	–	< 1
$\lvert V_{cb}\rvert \cdot 10^3$	40.9 ± 1.0	42.1 ± 0.7	< 1
B_K	0.766 ± 0.010	0.841 ± 0.078	< 1
$BR(B \to \tau\nu)[10^{-4}]$	1.14 ± 0.22	0.811 ± 0.061	~ 1.4
$BR(B_s \to ll)[10^{-9}]$	2.9 ± 0.7	3.92 ± 0.16	~ 1.3
$BR(B_d \to ll)[10^{-9}]$	0.37 ± 0.15	0.115 ± 0.007	~ 1.7
$A_{SL}^d \cdot 10^3$	-4.8 ± 5.2	0.012 ± 0.002	< 1
$A_{\mu\mu} \cdot 10^3$	-7.9 ± 2.0	-0.12 ± 0.02	~ 3.9

inclusives vs exclusives

only exclusive values

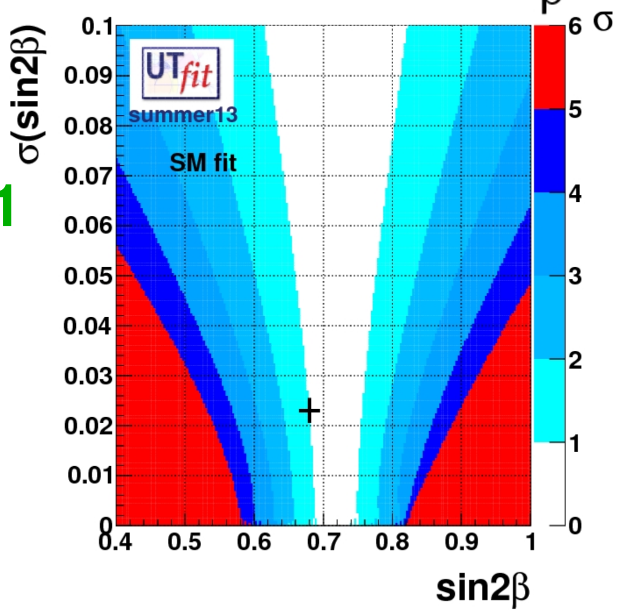


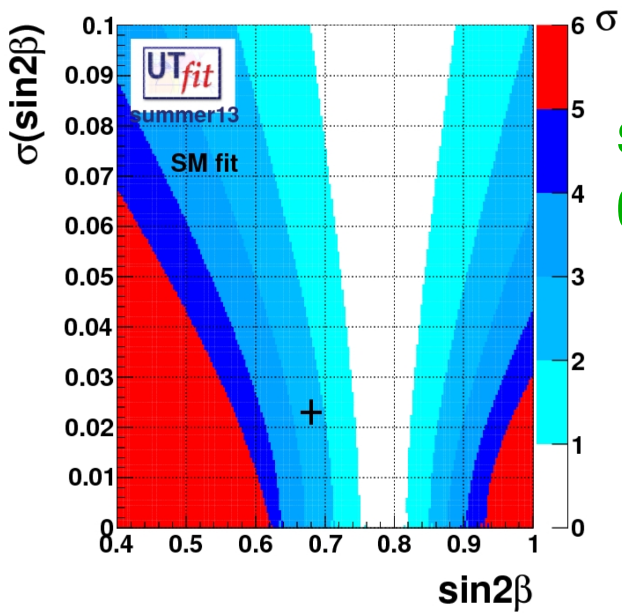


only inclusive values

$\sin2\beta_{UTfit}$ = 0.720 ± 0.031

~1.0σ





$\sin2\beta_{UTfit}$ = 0.782 ± 0.035

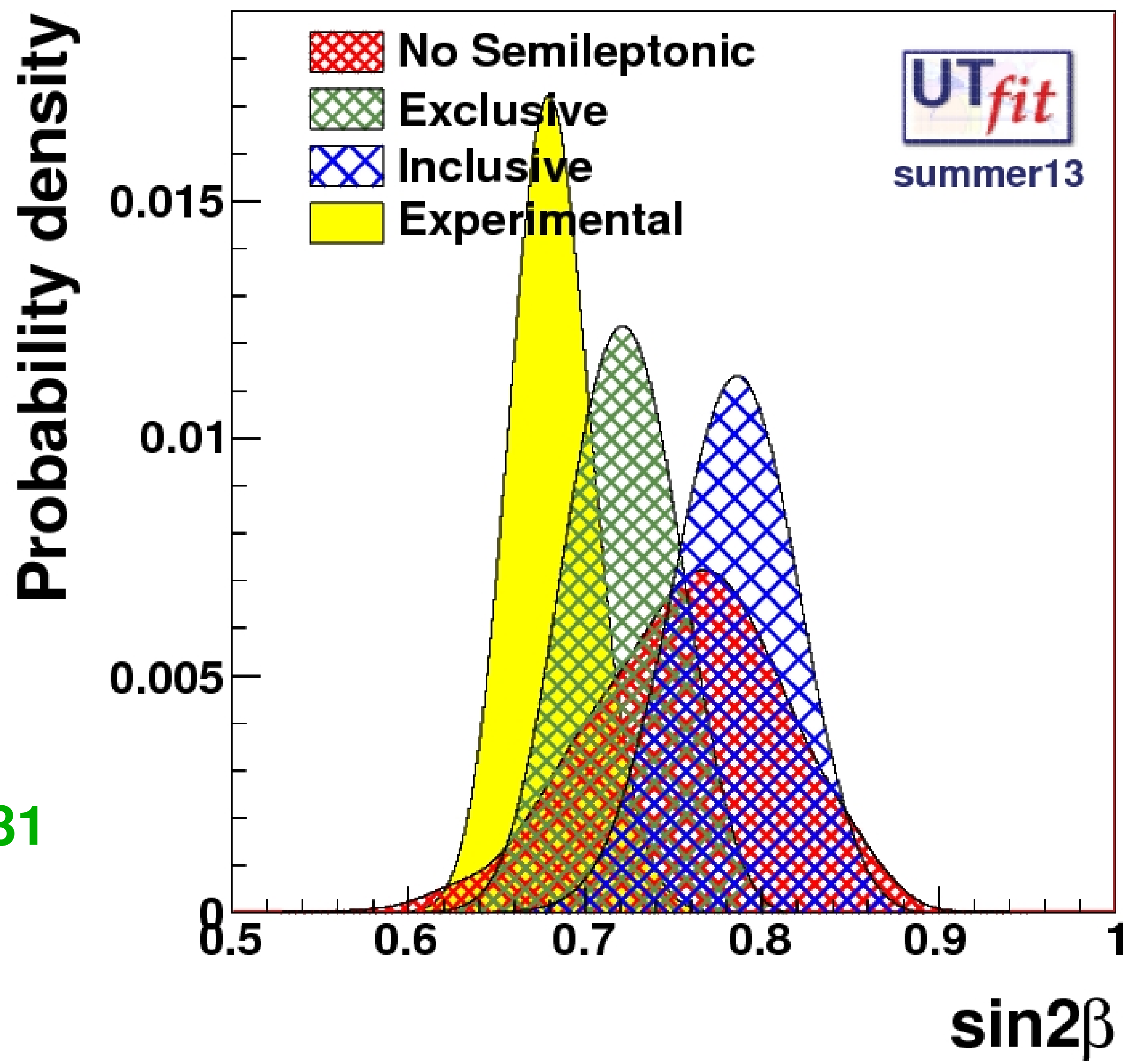
~2.4σ

inclusives vs exclusives

only exclusive values

$\sin 2\beta_{UTfit}$ = 0.720 ± 0.031

~1.0σ



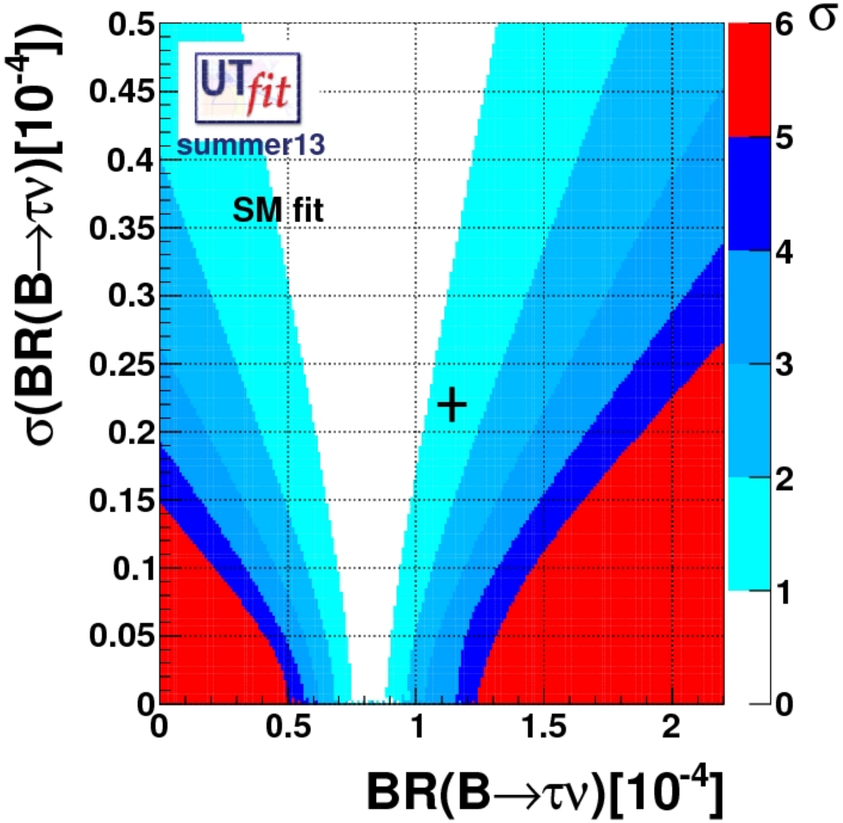
only inclusive values

$\sin 2\beta_{UTfit}$ = 0.782 ± 0.035

~2.4σ

more standard model predictions:

$BR(B\to\tau\nu) = (1.14 \pm 0.22)\ 10^{-4}$



~1.4σ

indirect determinations from UT

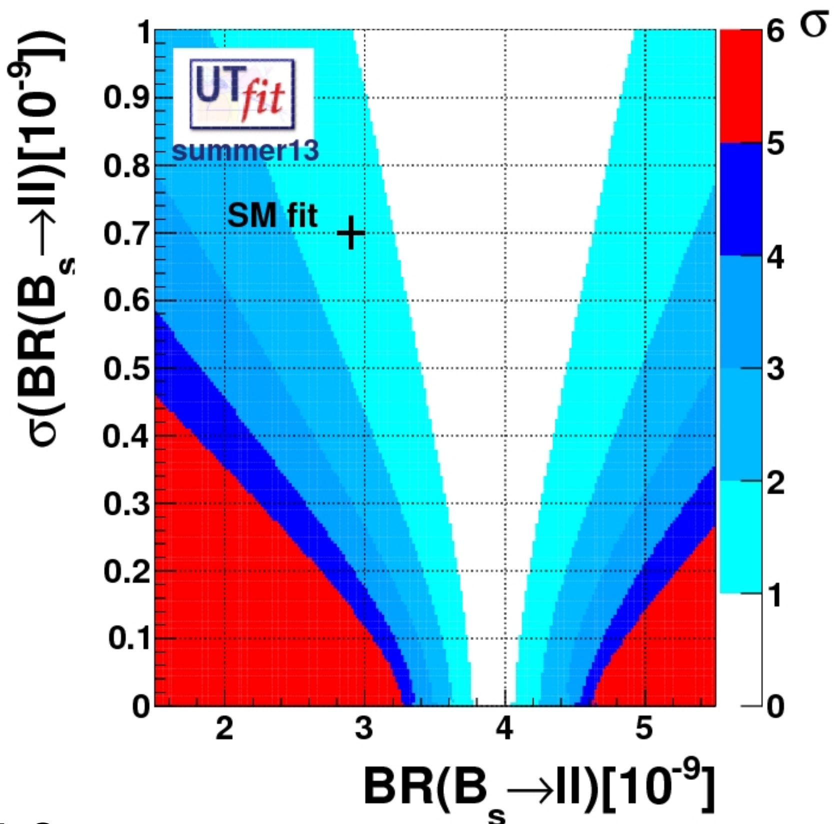
$BR(B\to\tau\nu) = (0.811 \pm 0.061)\ 10^{-4}$

M.Bona et al, 0908.3470 [hep-ph]

more standard model predictions:

from CMS+LHCb

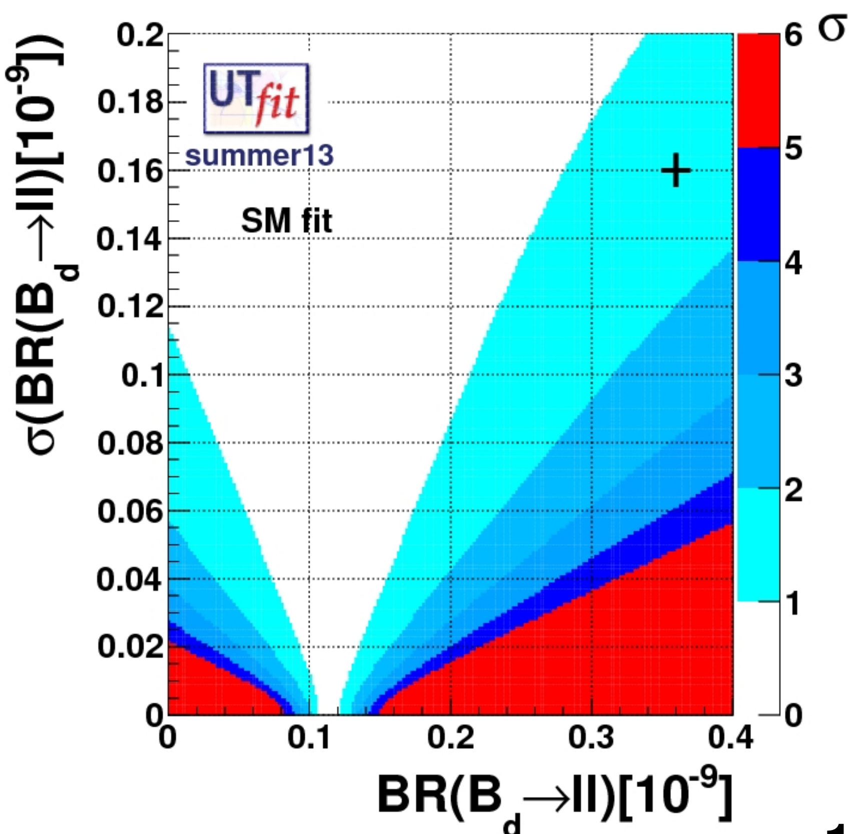
$BR(B_s \to \mu\mu) = (2.9 \pm 0.7)\ 10^{-9}$



~1.3σ

from CMS+LHCb

$BR(B_d \to \mu\mu) = (3.7 \pm 1.5)\ 10^{-10}$



~1.7σ

indirect determinations from UT

$BR(B_s \to ll) = (3.92 \pm 0.16)\ 10^{-9}$

$BR(B_d \to ll) = (1.15 \pm 0.07)\ 10^{-10}$

time-integration included

predictions on lattice parameters:

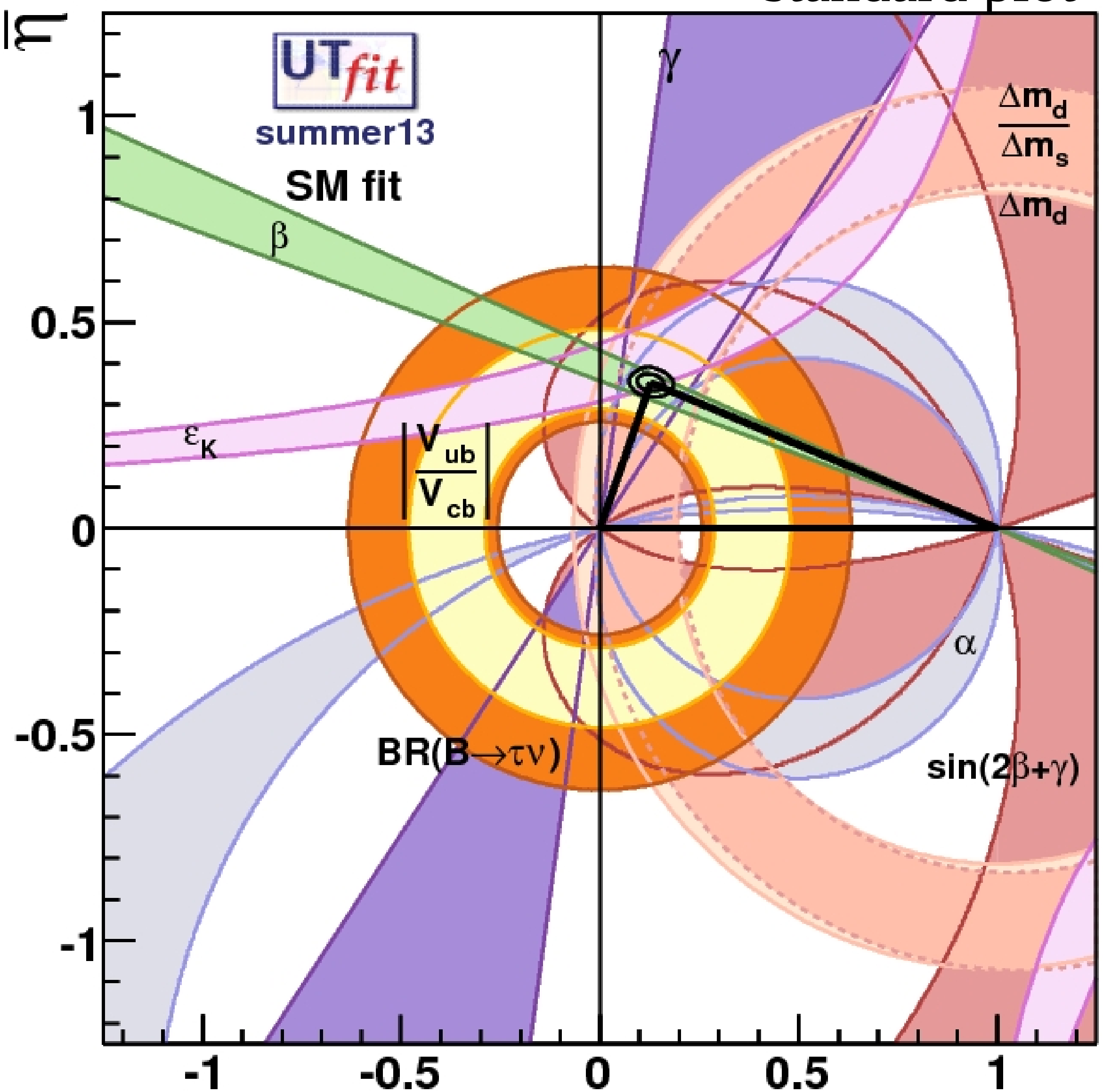
preliminary for this workshop

Observables	Measurement	Prediction	Pull (#σ)
B_K	0.766 ± 0.010	0.841 ± 0.078	0.9
f_{Bs}	0.2277 ± 0.0045	0.2270 ± 0.0065	< 0.5
f_{Bs}/f_{Bd}	1.202 ± 0.022	1.19 ± 0.06	< 0.5
B_{Bs}	0.875 ± 0.040	0.879 ± 0.045	< 0.5
B_{Bs}/B_{Bd}	1.06 ± 0.11	1.137 ± 0.076	0.5

obtained excluding the given constraint from the fit

Including NNLO ε_K corrections:

standard plot



preliminary for this workshop

levels @
95% Prob

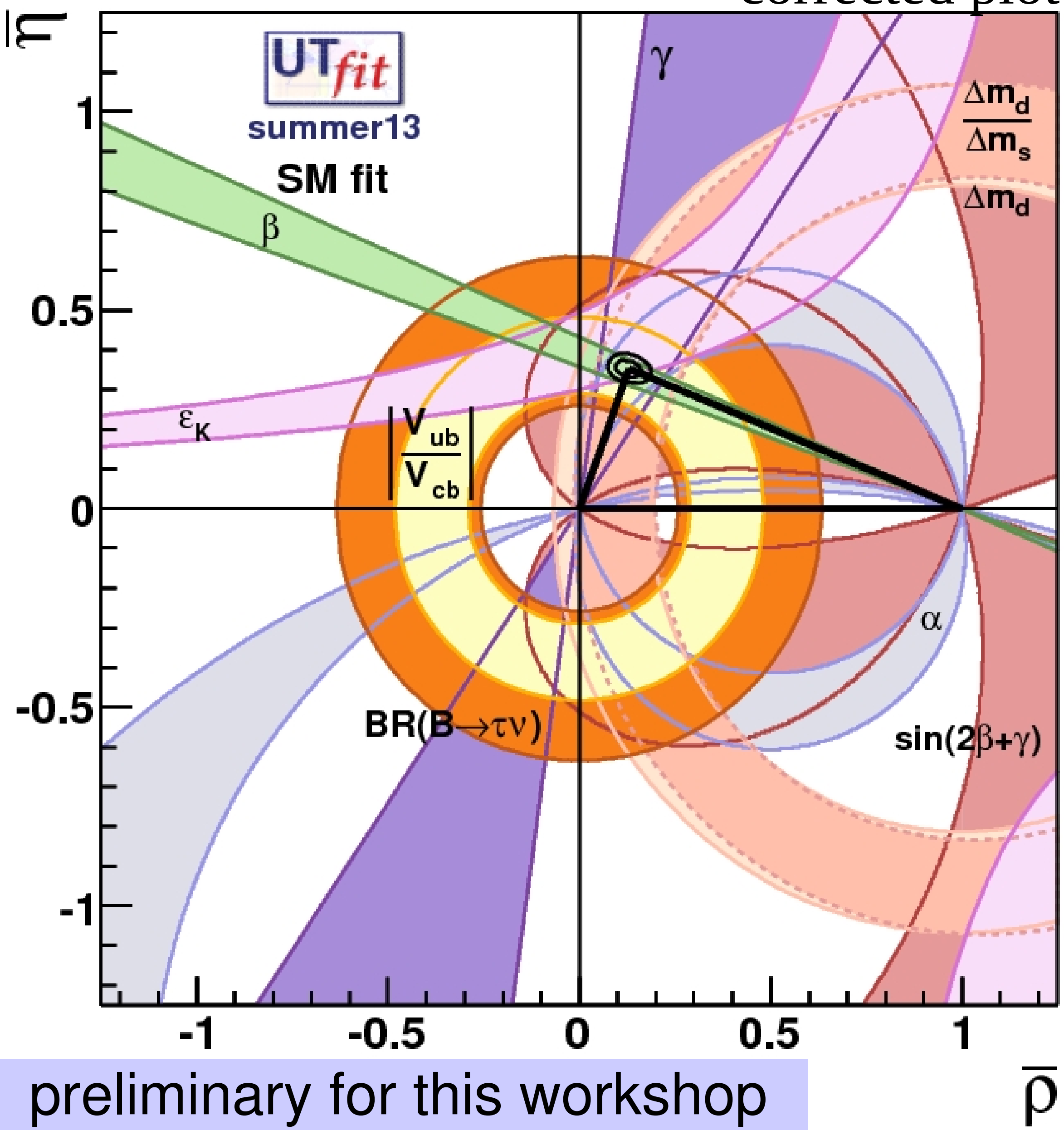
standard results

$\bar{\rho}$ = 0.129 ± 0.024
$\bar{\eta}$ = 0.353 ± 0.016

Including NNLO ε_K corrections:

Brod, Gorbahn
arXiv:1108.2036
arXiv: 1007.0684

corrected plot



preliminary for this workshop

levels @
95% Prob

corrected results

$\bar{\rho}$ = 0.130 ± 0.025
$\bar{\eta}$ = 0.352 ± 0.016

standard results

$\bar{\rho}$ = 0.129 ± 0.024
$\bar{\eta}$ = 0.353 ± 0.016

UT analysis including new physics

fit simultaneously for the CKM and
the NP parameters (generalized UT fit)

- add most general loop NP to all sectors
- use all available experimental info
- find out NP contributions to ΔF=2 transitions

B_d and B_s mixing amplitudes
(2+2 real parameters):

$$A_q = C_{B_q} e^{2i\phi_{B_q}} A_q^{SM} e^{2i\phi_q^{SM}} = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_q^{NP} - \phi_q^{SM})}\right) A_q^{SM} e^{2i\phi_q^{SM}}$$

$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM}$$
$$A_{CP}^{B_d \to J/\psi K_s} = \sin 2(\beta + \phi_{B_d})$$
$$A_{SL}^q = \mathrm{Im}\left(\Gamma_{12}^q / A_q\right)$$

$$\varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$
$$A_{CP}^{B_s \to J/\psi \phi} \sim \sin 2(-\beta_s + \phi_{B_s})$$
$$\Delta\Gamma^q / \Delta m_q = \mathrm{Re}\left(\Gamma_{12}^q / A_q\right)$$

new-physics-specific constraints

semileptonic asymmetries:

$$A^s_{\rm SL} \equiv \frac{\Gamma(\bar{B}_s \to \ell^+ X) - \Gamma(B_s \to \ell^- X)}{\Gamma(\bar{B}_s \to \ell^+ X) + \Gamma(B_s \to \ell^- X)} = {\rm Im}\left(\frac{\Gamma^s_{12}}{A^{\rm full}_s}\right)$$

sensitive to NP effects in both size and phase

B factories, CDF + D0 + LHCb

$A_{SL}(B_d)[10^{-3}] = 3.2 \pm 2.9$, $A_{SL}(B_s)[10^{-3}] = -4.8 \pm 5.2$

same-side dilepton charge asymmetry:

D0 arXiv:1106.6308

admixture of B_s and B_d so sensitive to NP effects in both systems

$$A^{\mu\mu}_{\rm SL} \times 10^3 = -7.9 \pm 2.0$$

$$A^{\mu\mu}_{\rm SL} = \frac{f_d \chi_{d0} A^d_{\rm SL} + f_s \chi_{s0} A^s_{\rm SL}}{f_d \chi_{d0} + f_s \chi_{s0}}$$

lifetime τ^{FS} in flavour-specific final states:

average lifetime is a function to the width and the width difference (independent data sample)

$$\tau^{\rm FS}_{B_s}\ [\rm ps] = 1.417 \pm 0.042$$

HFAG

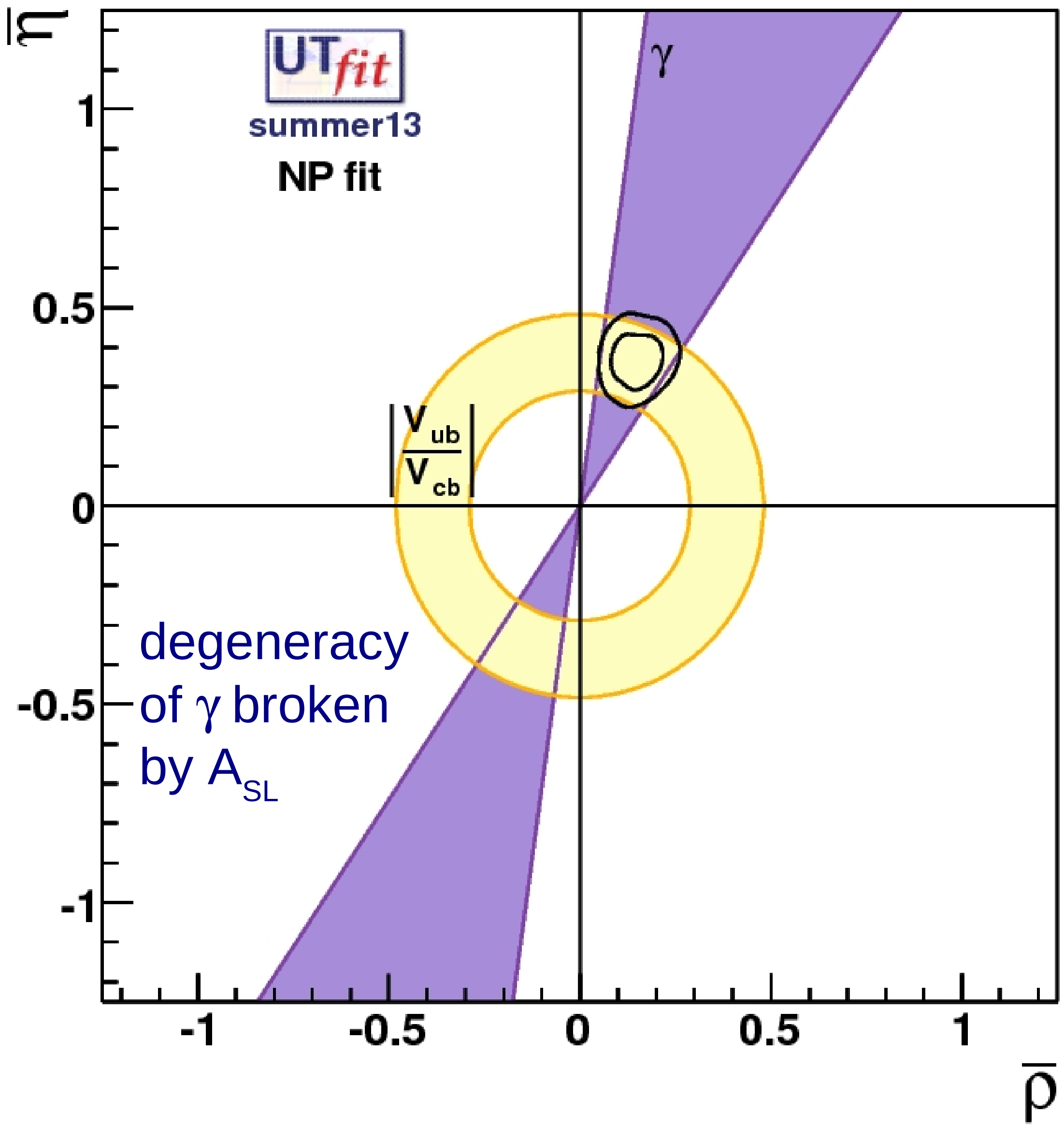
$$\tau^{FS}_{B_s} = \frac{1}{\Gamma_s} \frac{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$

$\phi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$

angular analysis as a function of proper time and b-tagging. Additional sensitivity from the $\Delta\Gamma_s$ terms

ϕ_s: LHCb: Gaussian
$\Delta\Gamma_s$: average: Gaussian

NP analysis results



$\bar{\rho} = 0.150 \pm 0.046$

$\bar{\eta} = 0.369 \pm 0.049$

SM is

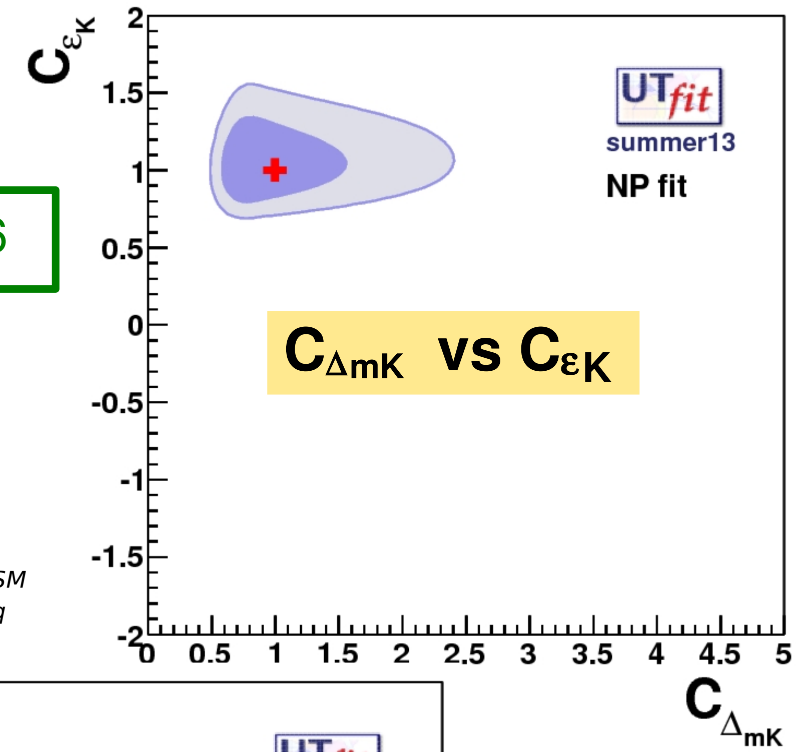
$\bar{\rho} = 0.129 \pm 0.024$

$\bar{\eta} = 0.355 \pm 0.016$

NP parameter results

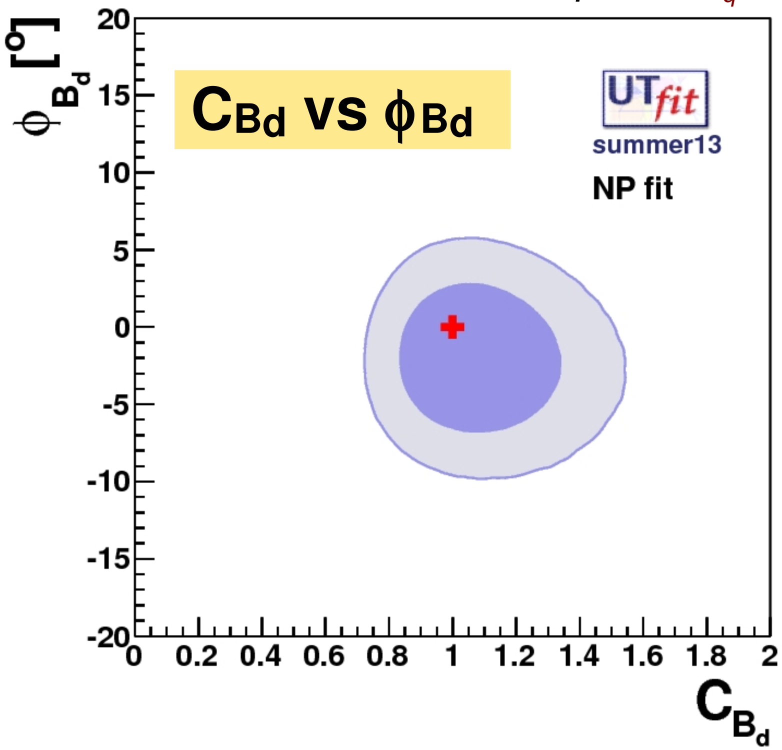
dark: 68%
light: 95%
SM: red cross

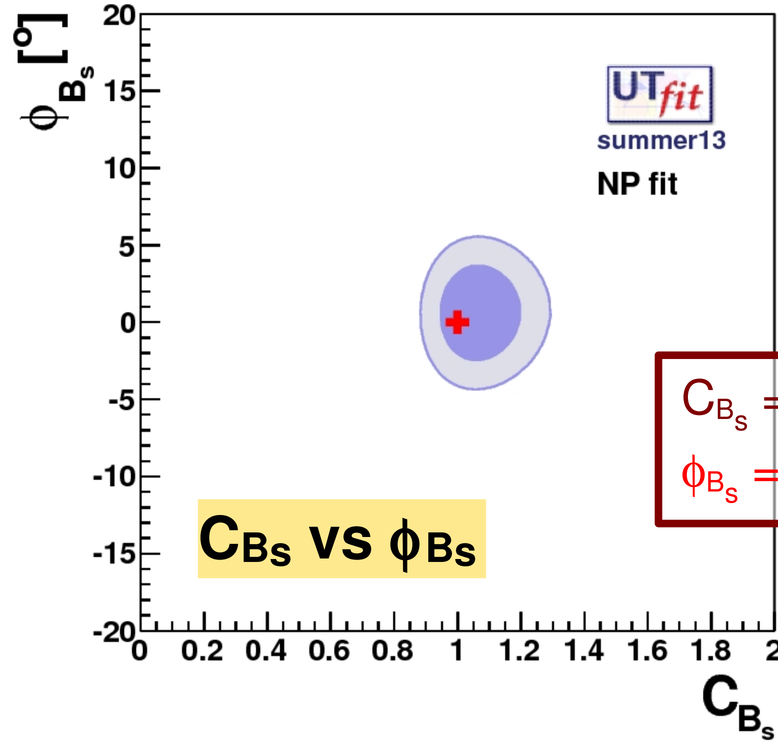
$C_{\varepsilon_K} = 1.08 \pm 0.16$



$C_{B_d} = 1.10 \pm 0.17$
$\phi_{B_d} = (-2.1 \pm 3.2)°$

$$A_q = C_{B_q} e^{2i\varphi_{B_q}} A_q^{SM} e^{2i\varphi_q^{SM}}$$

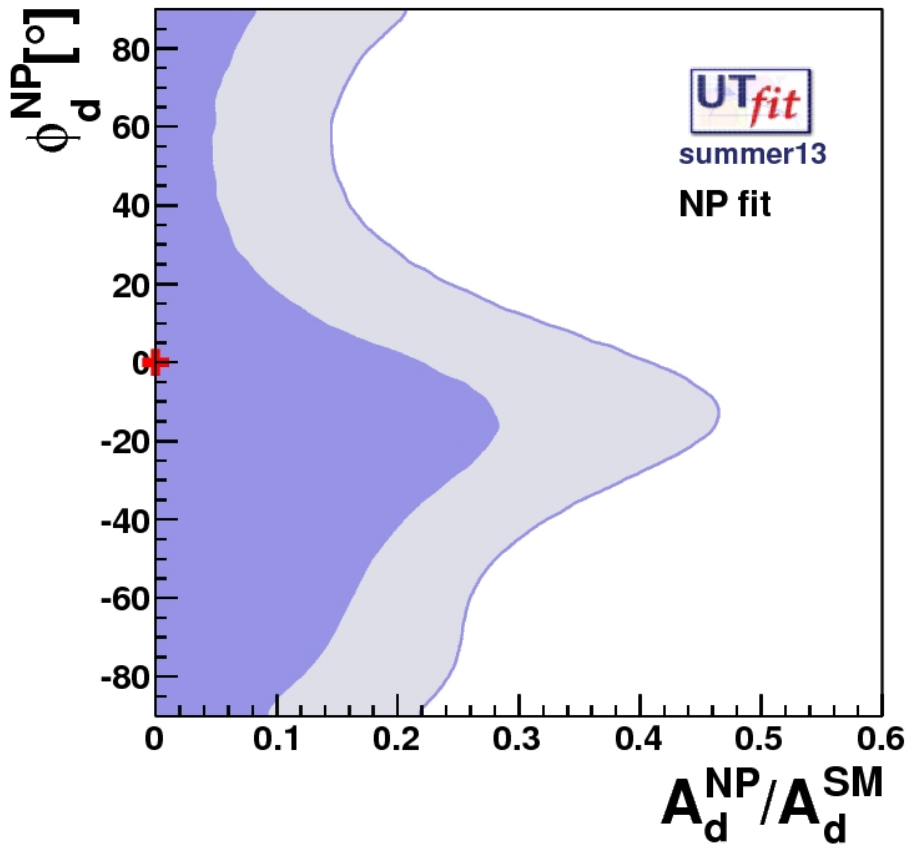


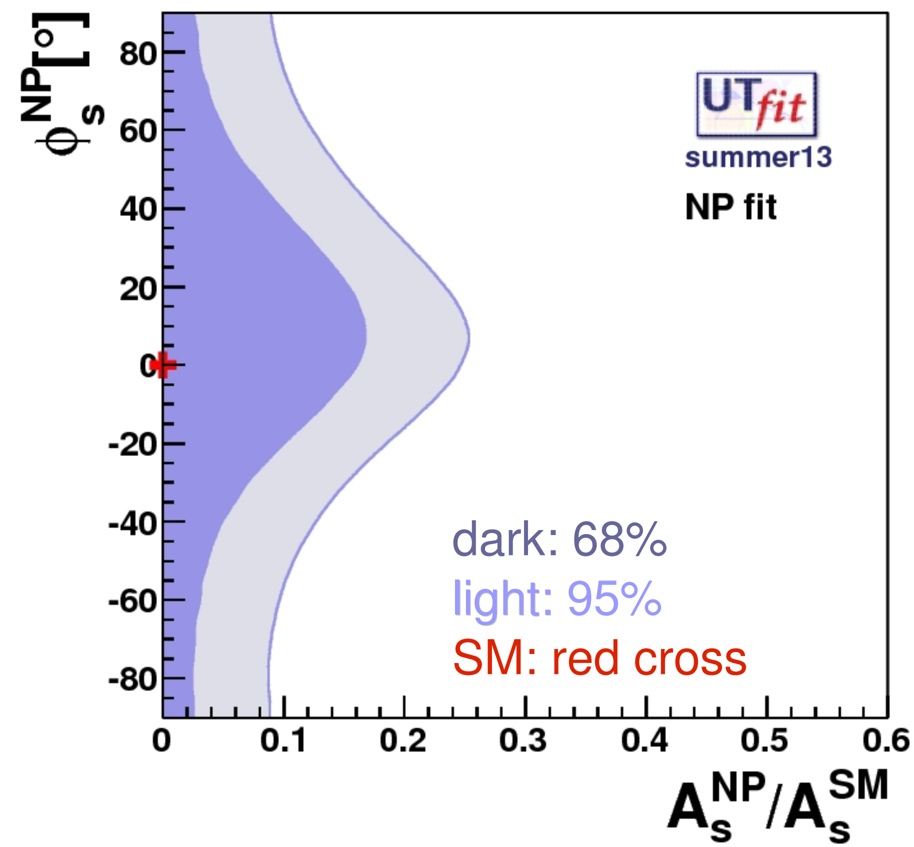


$C_{B_s} = 1.08 \pm 0.09$
$\phi_{B_s} = (0.6 \pm 2.0)°$

NP parameter results

$$A_q = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\varphi_q^{NP} - \varphi_q^{SM})}\right) A_q^{SM} e^{2i\varphi_q^{SM}}$$





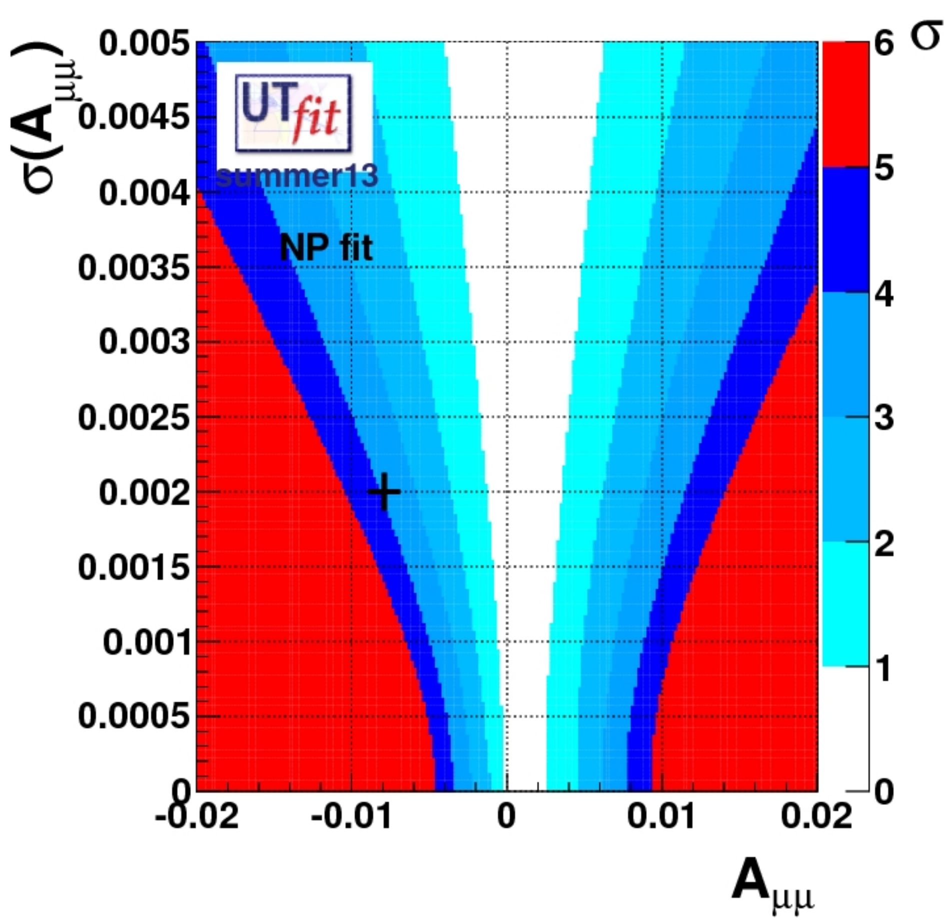
The ratio of NP/SM amplitudes is:

< 28% @68% prob. (47% @95%) in B_d mixing

< 17% @68% prob. (26% @95%) in B_s mixing

see also Lunghi & Soni, Buras et al., Ligeti et al.

compatibility plot with NP fit



The D0 dimuon asymmetry remains @ 3.9σ

testing the new-physics scale

R
G
E

At the high scale

new physics enters according to its specific features

At the low scale

use OPE to write the most general effective Hamiltonian.
the operators have different chiralities than the SM
NP effects are in the Wilson Coefficients C

$$\mathcal{H}_{\rm eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i Q_i^{bq} + \sum_{i=1}^{3} \tilde{C}_i \tilde{Q}_i^{bq}$$

$$\begin{aligned}
Q_1^{q_i q_j} &= \bar{q}_{jL}^{\alpha} \gamma_\mu q_{iL}^{\alpha} \bar{q}_{jL}^{\beta} \gamma^\mu q_{iL}^{\beta} \,, \\
Q_2^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha} \bar{q}_{jR}^{\beta} q_{iL}^{\beta} \,, \\
Q_3^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta} \bar{q}_{jR}^{\beta} q_{iL}^{\alpha} \,, \\
Q_4^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha} \bar{q}_{jL}^{\beta} q_{iR}^{\beta} \,, \\
Q_5^{q_i q_j} &= \bar{q}_{jR}^{\alpha} q_{iL}^{\beta} \bar{q}_{jL}^{\beta} q_{iR}^{\alpha} \,.
\end{aligned}$$

NP effects are enhanced

- up to a factor 10 by the values of the matrix elements especially for transitions among quarks of different chiralities
- up to a factor 8 by RGE

M. Bona *et al.* (UTfit)
JHEP 0803:049,2008
arXiv:0707.0636

effective BSM Hamiltonian for ΔF=2 transitions

The Wilson coefficients C_i have in general the form

$$C_i(\Lambda) = F_i \frac{L_i}{\Lambda^2}$$

Putting bounds on the Wilson coefficients give insights into the NP scale in different NP scenarios that enter through F_i and L_i

F_i: function of the NP flavour couplings
L_i: loop factor (in NP models with no tree-level FCNC)
Λ: NP scale (typical mass of new particles mediating ΔF=2 transitions)

testing the TeV scale

$$C_i(\Lambda) = \frac{F_i L_i}{\Lambda^2}$$

The dependence of C on Λ changes on flavor structure.
We can consider different flavour scenarios:

- Generic: $C(\Lambda) = \alpha/\Lambda^2$ $F_i \sim 1$, arbitrary phase
- NMFV: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$ $F_i \sim |F_{SM}|$, arbitrary phase
- MFV: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$ $F_1 \sim |F_{SM}|$, $F_{i\neq 1} \sim 0$, SM phase

α (L_i) is the coupling among NP and SM

- $\alpha \sim 1$ for strongly coupled NP
- $\alpha \sim \alpha_W$ (α_S) in case of loop coupling through weak (strong) interactions

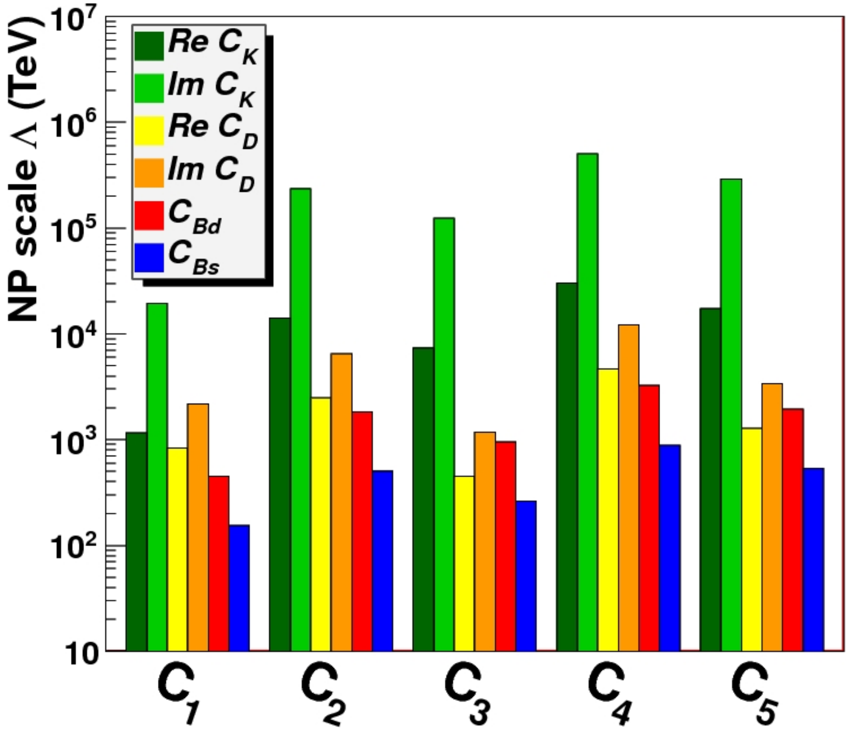
If no NP effect is seen
lower bound on NP scale Λ
if NP is seen
upper bound on NP scale Λ

F is the flavour coupling and so
F_{SM} is the combination of CKM factors for the considered process

results from the Wilson coefficients

Generic: $C(\Lambda) = \alpha/\Lambda^2$, $F_i \sim 1$, arbitrary phase

$\alpha \sim 1$ for strongly coupled NP



Lower bounds on NP scale (in TeV at 95% prob.)

Non-perturbative NP
$\Lambda > 5.0\ 10^5$ TeV

To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by α_s (~ 0.1) or by α_W (~ 0.03).

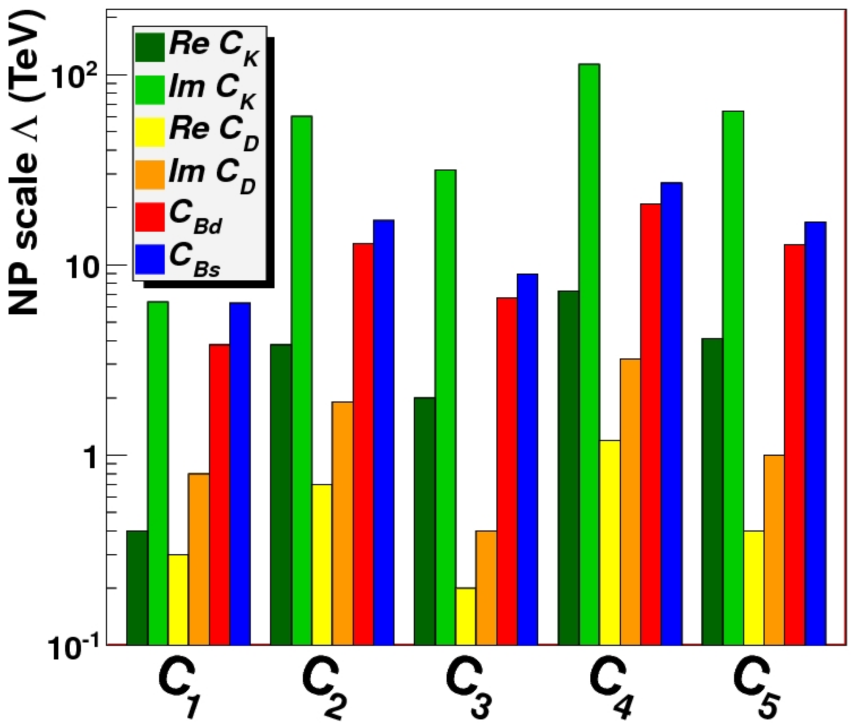
$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions

NP in α_W loops
$\Lambda > 1.5\ 10^4$ TeV

results from the Wilson coefficients

NMFV: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$, $F_i \sim |F_{SM}|$, arbitrary phase

$\alpha \sim 1$ for strongly coupled NP



Lower bounds on NP scale
(in TeV at 95% prob.)

To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by α_s (~ 0.1) or by α_W (~ 0.03).

Non-perturbative NP
$\Lambda > 113$ TeV

$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions

NP in α_W loops
$\Lambda > 3.4$ TeV

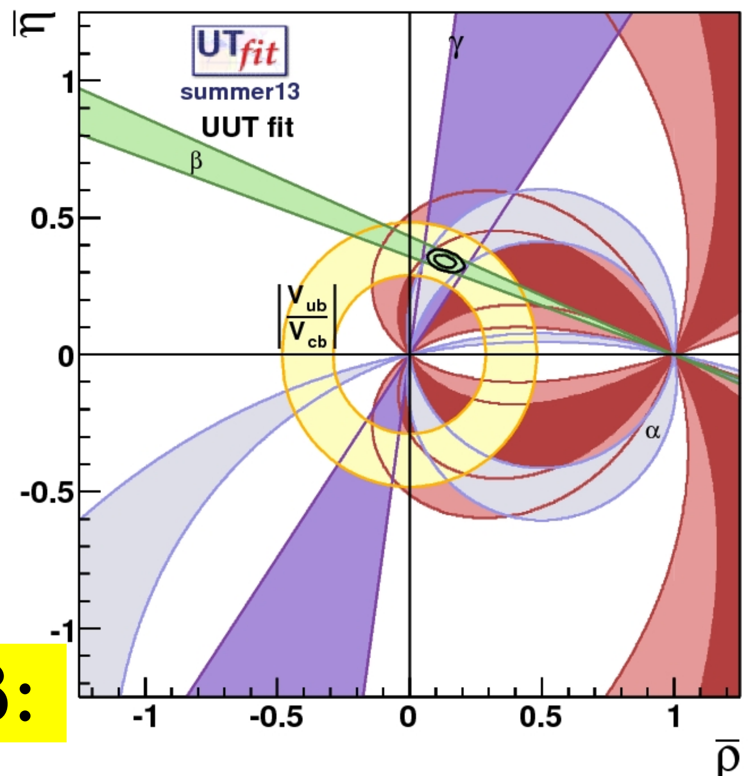
conclusions

- SM analysis displays good overall consistency
- Still open discussion on semileptonic inclusive vs exclusive
- UTA provides determination also of NP contributions to $\Delta F=2$ amplitudes. It currently leaves space for NP at the level of 15-20%
- So the scale analysis points to high scales for the generic scenario and even above LHC reach for weak coupling. Indirect searches become essential.
- Even if we don't see relevant deviations in the down sector, we might still find them in the up sector.

Back up slides

UUT and MFV:

Universal Unitarity Triangle (UUT):
unaffected by MFV-NP



$\bar{\rho}$ = 0.135 ± 0.029
$\bar{\eta}$ = 0.341 ± 0.017

SM is

$\bar{\rho}$ = 0.129 ± 0.024
$\bar{\eta}$ = 0.355 ± 0.016

low/moderate tanβ:

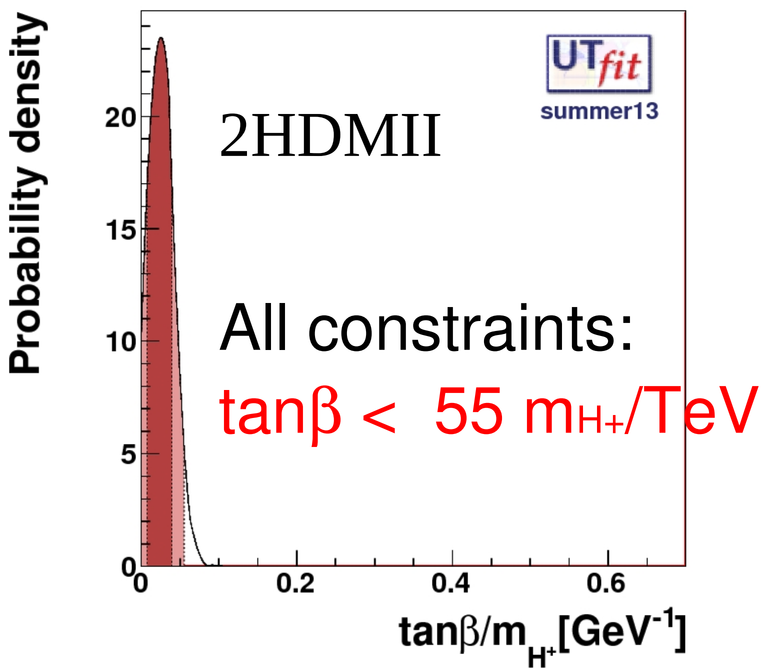
MFV: $Y_{u,d}$ only source of flavour and CPV
Bounds on MFV models @ low/moderate tanβ,
NP effects amount to a modification of the top loop:
in $\Delta F=2$, $S_0(x_t) \rightarrow S_0(x_t) + \delta S$,
with $\delta S=4c(\Lambda_{SM}/\Lambda)^2$ and Λ_{SM}~2.4 TeV

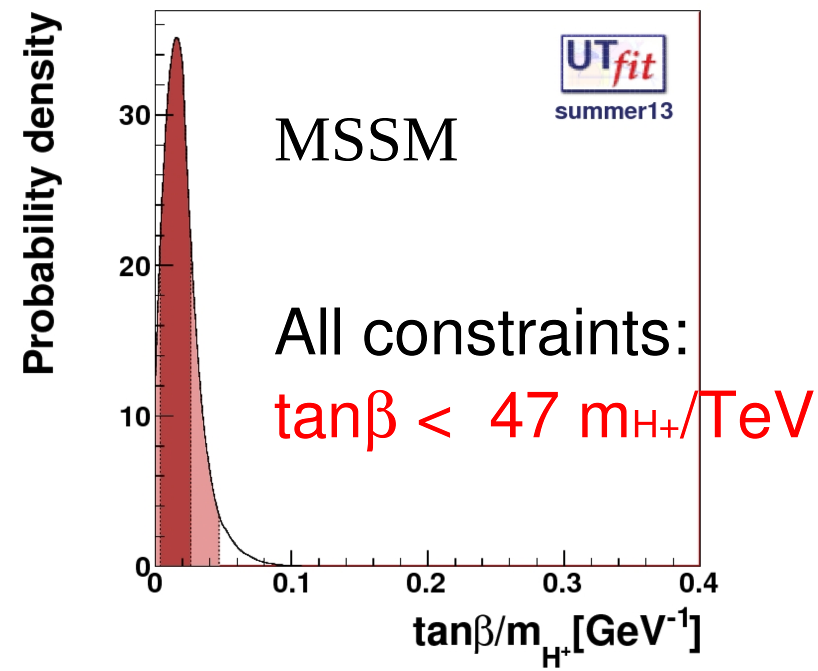
We find $\delta S \in [-0.28,0.48]$ @ 95% probability
This corresponds to Λ>6.9 TeV for c=1 and to Λ>9.1 TeV for c=-1

MFV at large tanβ:

For large tanβ, Y_b becomes important, and Higgs exchange can dominate over SM in helicity-suppressed amplitudes: $B\to\tau\nu$, $B_s\to\mu\mu$

- In 2HDMII, $(\tan\beta/m_{H+})^4$-enhanced contributions:
  $BR/BR_{SM} \sim (1 - m_B^2 \tan^2\beta/m_{H+}^2)^2$
- In the MSSM, loop effects induce $(\tan\beta/m_{H+})^6$-enhanced contributions to $B_s\to\mu\mu$ $(\mu A_t/m_{stop}^2 \tan^3\beta/m_{H+}^2)^2$

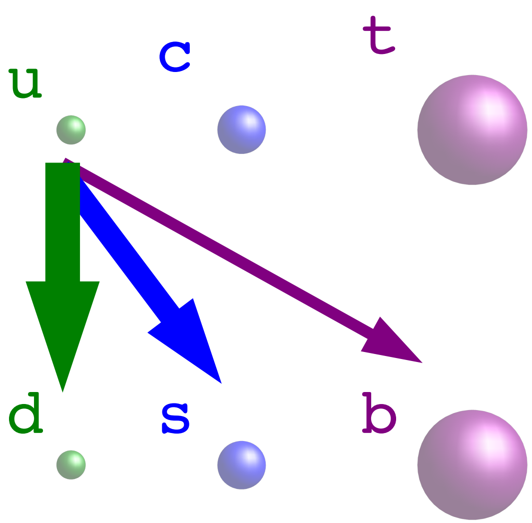


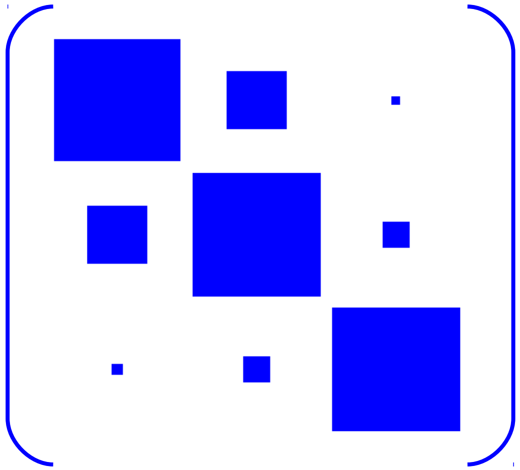


Flavour mixing and CP violation in the Standard Model

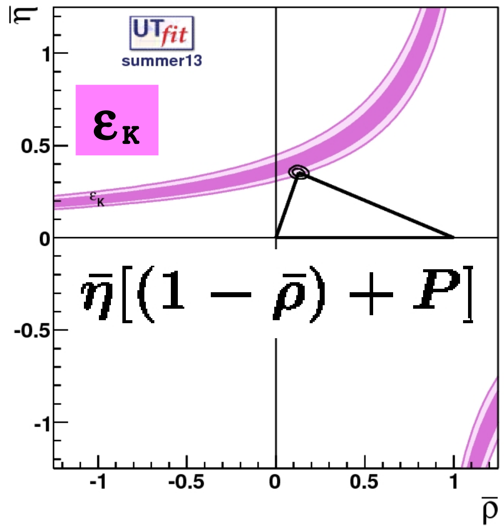
- The CP symmetry is violated in any field theory having in the Lagrangian at least one phase that cannot be re-absorbed
- The mass eigenstates are not eigenstates of the weak interaction. This feature of the Standard Model Hamiltonian produces the (unitary) mixing matrix V_{CKM}.

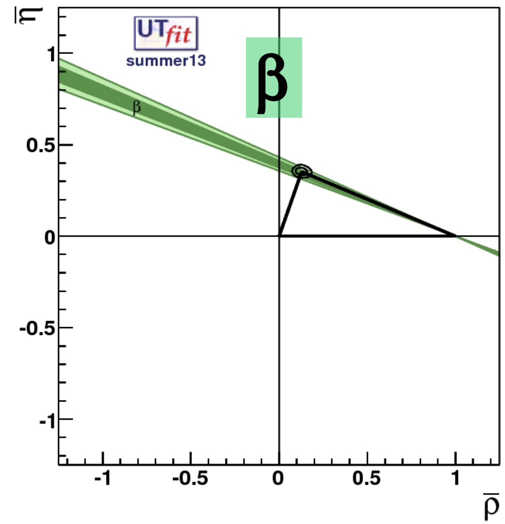
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

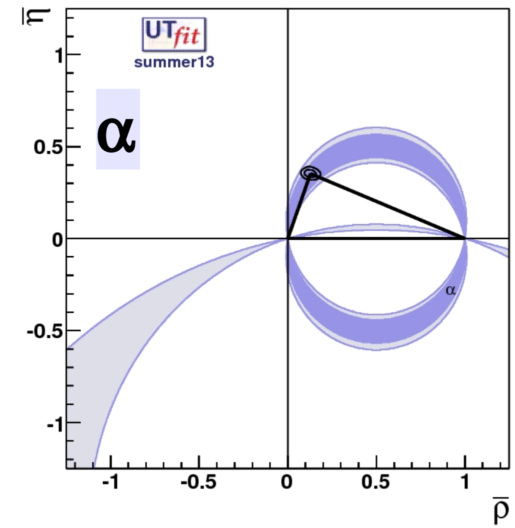


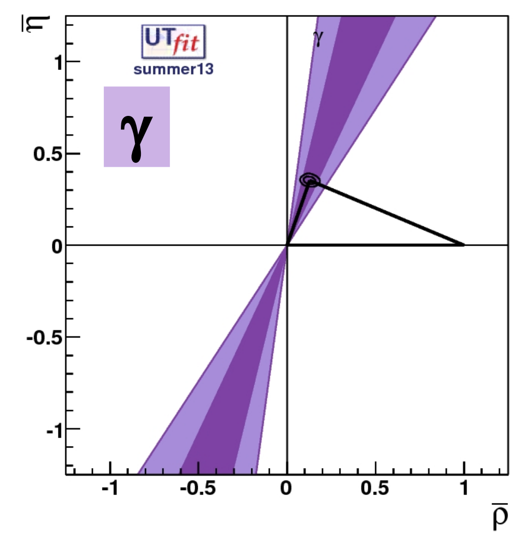


CP-violating inputs









ε_K from K-K mixing

$\rightarrow B_K = 0.766 \pm 0.010$ FLAG-2

sin2β from B → J/ψK⁰ + theory

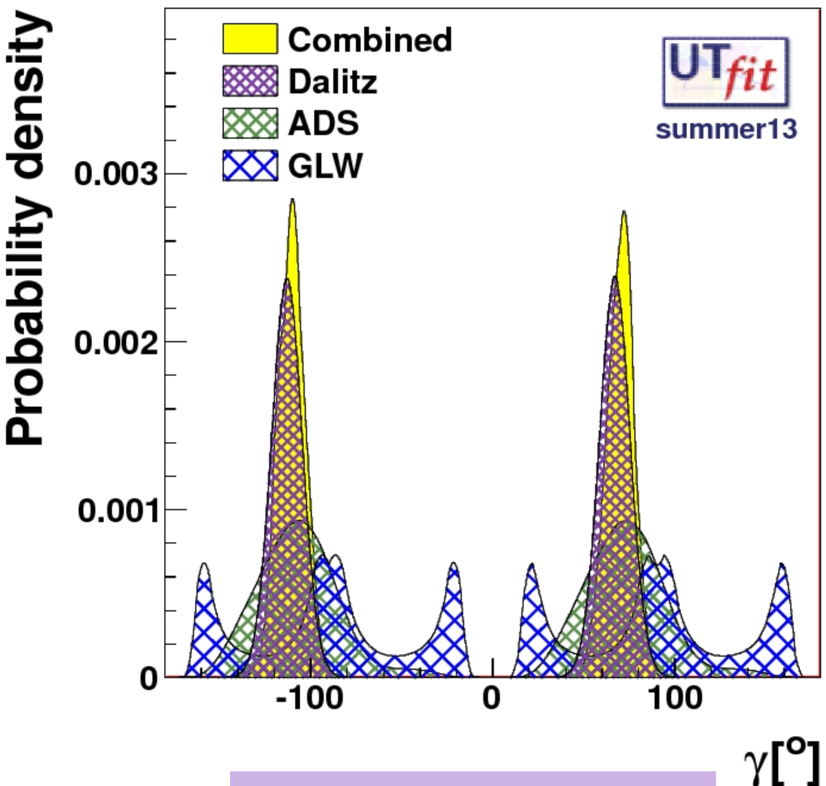
$\sin 2\beta(J/\psi K^0) = 0.680 \pm 0.023$ HFAG + CPS

α from ππ, ρρ, πρ decays:

combined: $(90.7 \pm 7.4)°$

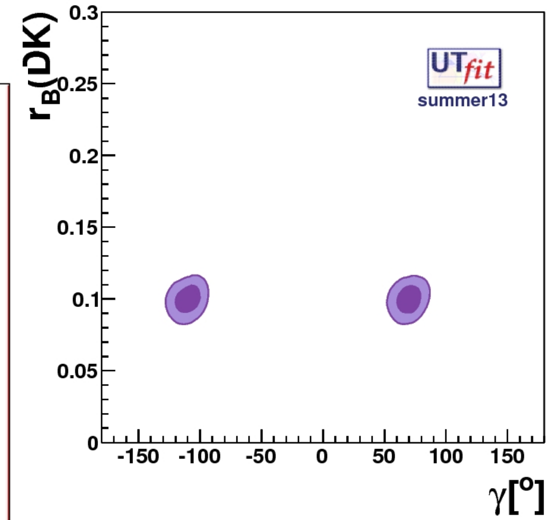
γ from B → DK decays (tree level)

γ and DK trees

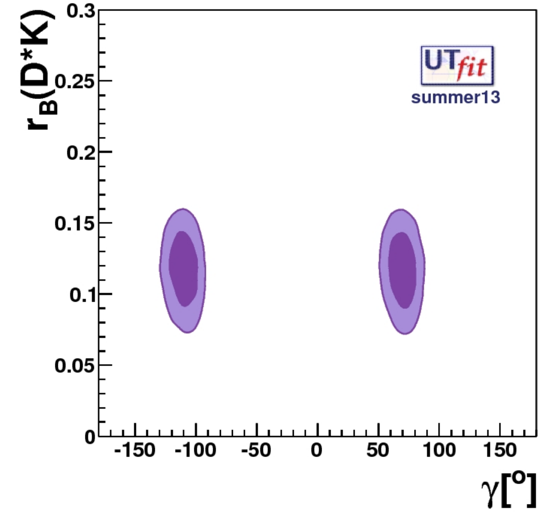


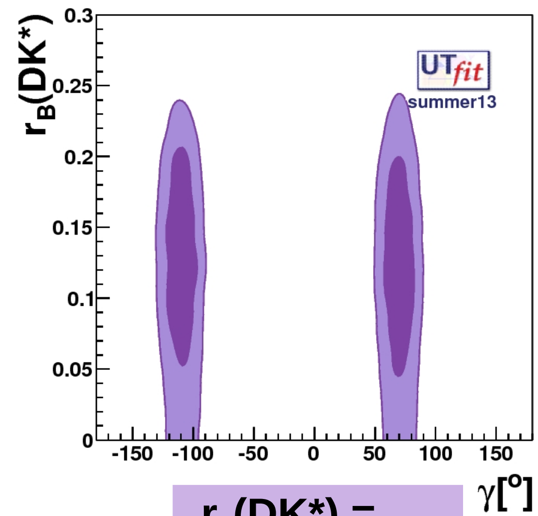
$\gamma = (70.1 \pm 7.1)^o$

$r_B(DK) =$
0.0999 ± 0.0059



$r_B(D^*K) =$
0.118 ± 0.018





$r_B(DK^*) =$
0.130 ± 0.057

new-physics-specific constraints

B meson mixing matrix element NLO calculation
Ciuchini et al. JHEP 0308:031,2003.

$$\frac{\Gamma_{12}^q}{A_q^{\rm full}} = -2\frac{\kappa}{C_{B_q}}\left\{e^{2\phi_{B_q}}\left(n_1+\frac{n_6 B_2+n_{11}}{B_1}\right)-\frac{e^{(\phi_q^{\rm SM}+2\phi_{B_q})}}{R_t^q}\left(n_2+\frac{n_7 B_2+n_{12}}{B_1}\right)\right.$$
$$+\frac{e^{2(\phi_q^{\rm SM}+\phi_{B_q})}}{R_t^{q^2}}\left(n_3+\frac{n_8 B_2+n_{13}}{B_1}\right)+e^{(\phi_q^{\rm Pen}+2\phi_{B_q})}C_q^{\rm Pen}\left(n_4+n_9\frac{B_2}{B_1}\right)$$
$$\left.-e^{(\phi_q^{\rm SM}+\phi_q^{\rm Pen}+2\phi_{B_q})}\frac{C_q^{\rm Pen}}{R_t^q}\left(n_5+n_{10}\frac{B_2}{B_1}\right)\right\}$$

C_{pen} and ϕ_{pen} are parameterize possible NP contributions from $b \rightarrow s$ penguins

UT analysis including NP

M.Bona *et al* (UTfit)
Phys.Rev.Lett. 97:151803,2006

	ρ, η	C_{Bd}, ϕ_{Bd}	$C_{\varepsilon K}$	C_{bs}, ϕ_{Bs}
V_{ub}/V_{cb}	X			
γ (DK)	X			
ε_K	X		X	
sin2β	X	X		
Δm_d	X	X		
α	X	X		
A_{SL} B_d	X	X X		
$\Delta\Gamma_d/\Gamma_d$	X	X X		
$\Delta\Gamma_s/\Gamma_s$	X			X X
Δm_s				X
A_{CH}	X	X X		X X

model independent assumptions

SM → SM+NP

tree level

$(V_{ub}/V_{cb})^{SM}$ → $(V_{ub}/V_{cb})^{SM}$

γ^{SM} → γ^{SM}

Bd Mixing

β^{SM} → $\beta^{SM}+\phi_{Bd}$

α^{SM} → $\alpha^{SM}-\phi_{Bd}$

Δm_d → $C_{Bd}\Delta m_d$

Bs Mixing

Δm_s^{SM} → $C_{Bs}\Delta m_s^{SM}$

β_s^{SM} → $\beta_s^{SM}+\phi_{Bs}$

K Mixing

ε_K^{SM} → $C\varepsilon_K\ \varepsilon_K^{SM}$

contribution to the mixing amplitutes

analytic expression for the contribution to the mixing amplitudes

Lattice QCD

$$\langle \bar{B}_q | \mathcal{H}_{\text{eff}}^{\Delta B=2} | B_q \rangle_i = \sum_{j=1}^{5} \sum_{r=1}^{5} \left(b_j^{(r,i)} + \eta\, c_j^{(r,i)} \right) \eta^{a_j}\, C_i(\Lambda) \langle \bar{B}_q | Q_r^{bq} | B_q \rangle$$

arXiv:0707.0636: for "magic numbers" a,b and c, $\eta = \alpha_S(\Lambda)/\alpha_S(m_t)$
(numerical values updated last in summer'12)

analogously for the K system

$$\langle \bar{K}^0 | \mathcal{H}_{\text{eff}}^{\Delta S=2} | K^0 \rangle_i = \sum_{j=1}^{5} \sum_{r=1}^{5} \left(b_j^{(r,i)} + \eta\, c_j^{(r,i)} \right) \eta^{a_j}\, C_i(\Lambda)\, R_r \langle \bar{K}^0 | Q_1^{sd} | K^0 \rangle$$

To obtain the p.d.f. for the Wilson coefficients $C_i(\Lambda)$ at the new-physics scale, we switch on one coefficient at a time in each sector and calculate its value from the result of the NP analysis.

The future of CKM fits

LHCb reach from:
O. Schneider, 1st LHCb Collaboration Upgrade Workshop

SuperB reach from:
SuperB Conceptual Design Report, arXiv:0709.0451

	LHCb 2015 10/fb (5 years)	SuperB 1/ab (1 month at Y(5S))
Δm_s	0.07%(+0.5%)	no
A^s_{SL}	?	0.006
ϕ_s ($J/\psi\ \phi$)	0.01+syst	0.14
		75/ab (5 years)
$\sin 2\beta$ ($J/\psi\ K_s$)	0.010	0.005
γ (all methods)	2.4°	1-2°
α (all methods)	4.5°	1-2°
$\lvert V_{cb}\rvert$ (all methods)	no	< 1%
$\lvert V_{ub}\rvert$ (all methods)	no	1-2%

Hadronic matrix element	Current lattice error	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9% (22% on 1-f_+)	0.4% (10% on 1-f_+)	< 0.1% (2.4% on 1-f_+)
$\hat{B}_K$	11%	3%	1%
f_B	14%	2.5 - 4.0%	1 – 1.5%
$f_{B_s}B_{B_s}^{1/2}$	13%	3 - 4%	1 – 1.5%
ξ	5% (26% on ξ-1)	1.5 - 2 % (9-12% on ξ-1)	0.5 – 0.8 % (3-4% on ξ-1)
$\mathcal{F}_{B\to D/D^*l\nu}$	4% (40% on 1-$\mathcal{F}$)	1.2% (13% on 1-$\mathcal{F}$)	0.5% (5% on 1-$\mathcal{F}$)
$f_+^{B\pi}, \ldots$	11%	4 - 5%	2 – 3%
$T_1^{B\to K^*/\rho}$	13%	----	3 – 4%

S. Sharpe @ Lattice QCD: Present and Future, Orsay, 2004 and report of the U.S. Lattice QCD Executive Committee