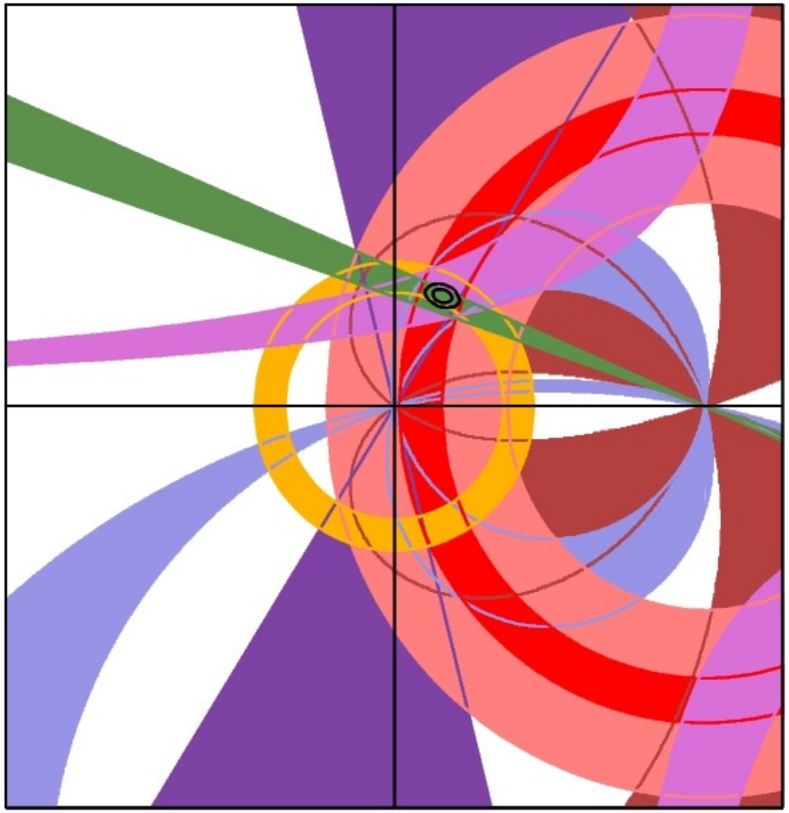
Standard Model updates and new physics analysis with the Unitarity Triangle fit



Marcella Bona

Queen Mary University of London

EPS 2011,
Grenoble, France
July 22nd, 2011

M.Bona *et al.*, UTfit
JHEP0507:028, 2005

www.utfit.org

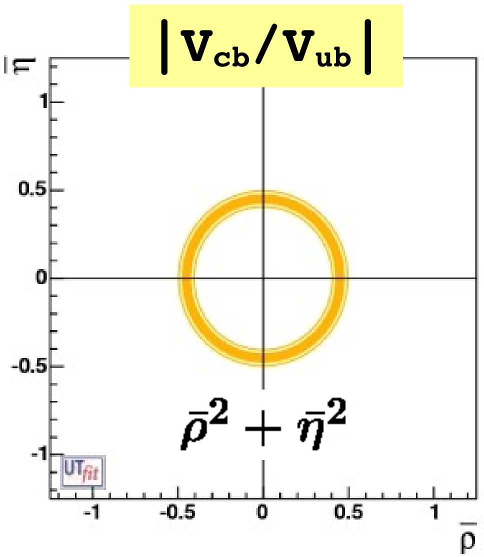
**A. Bevan, M. Bona, M. Ciuchini,
D. Derkach, E. Franco, V. Lubicz,
G. Martinelli, F. Parodi, M. Pierini,
C. Schiavi, L. Silvestrini, A. Stocchi,
V. Sordini, C. Tarantino and V. Vagnoni**

unitarity Triangle analysis in the SM

→ **SM UT analysis:**

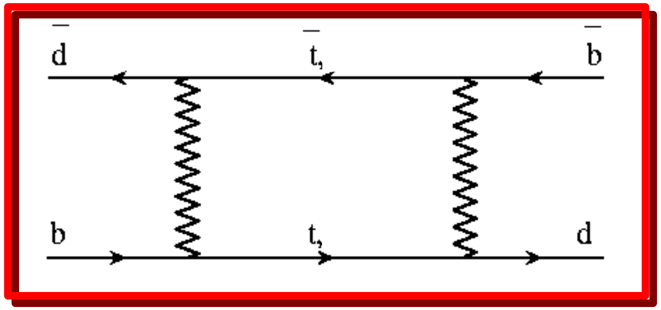
- **provide the best determination of CKM parameters**
- **test the consistency of the SM ("direct" vs "indirect" determinations)**
- **provide predictions for SM observables (ex. sin2β, Δm_s, ...)**

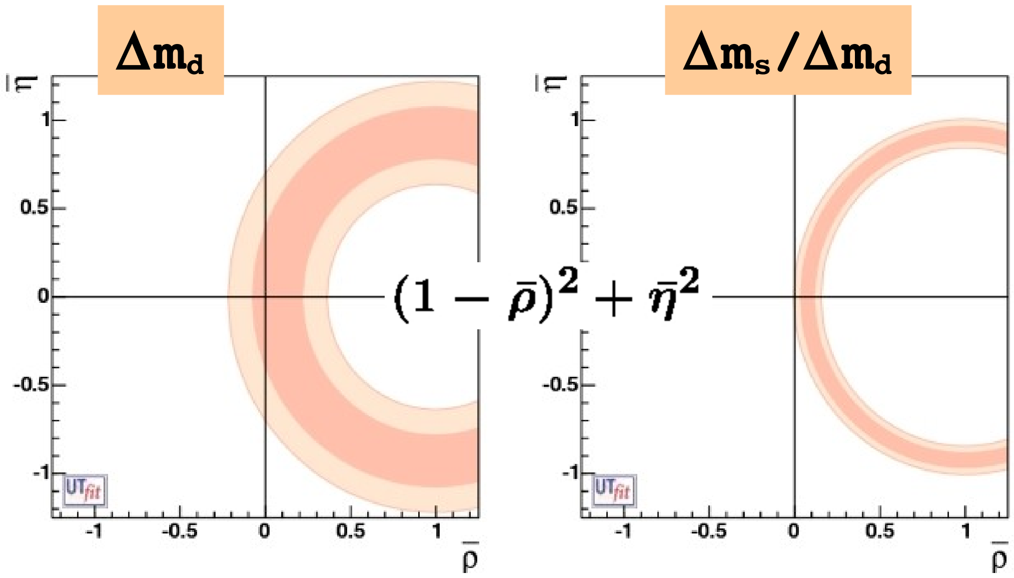
CP-conserving inputs



$|V_{ub}|/|V_{cb}|$~R_b (tree-level)

B_d-B_d and B_s-B_s mixing





V_{cb} and V_{ub}

should update to
39.5 ± 1.0

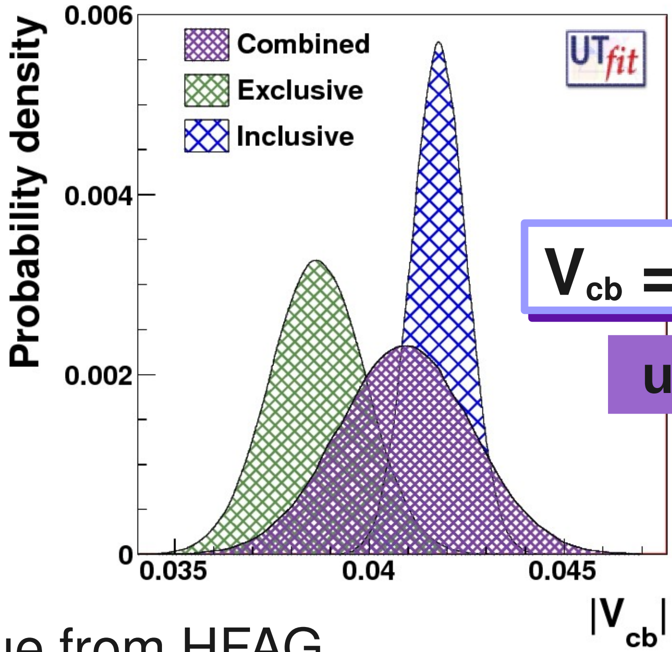
Laiho *et al*

V_{cb} *(excl)* = (38.6 ± 1.2) 10^{-3}

HFAG

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

~2.2σ discrepancy



UTfit input value

V_{cb} = (40.9 ± 1.7) 10^{-3}

uncertainty ~ 4%

new preliminary value from HFAG
3.26 ± 0.30

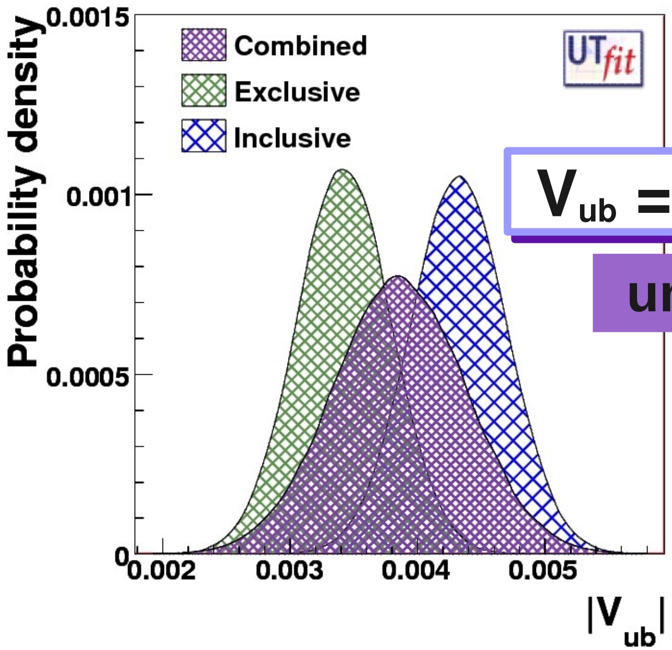
Laiho *et al*

V_{ub} *(excl)* = (3.42 ± 0.37) 10^{-3}

UTfit from HFAG

V_{ub} *(incl)* = (4.32 ± 0.38) 10^{-3}

~1.7σ discrepancy



UTfit input value

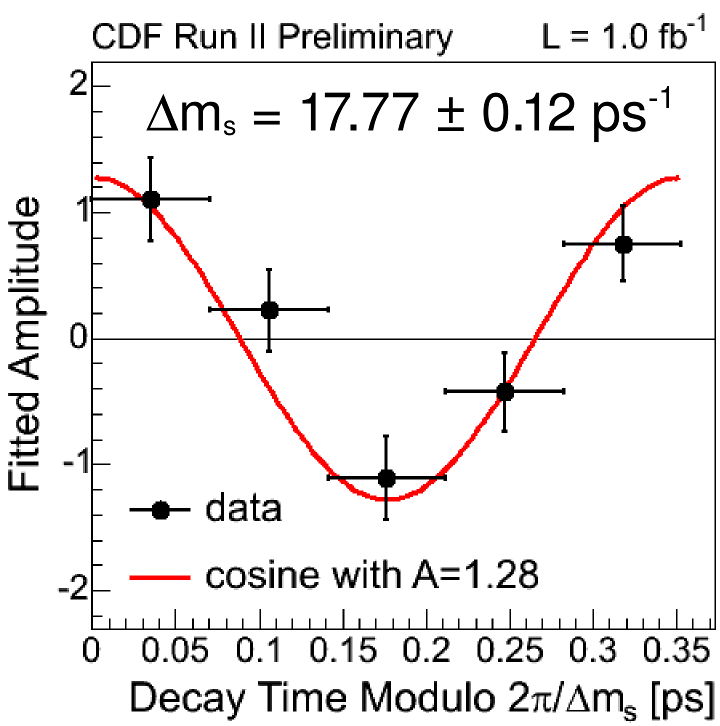
V_{ub} = (3.86 ± 0.52) 10^{-3}

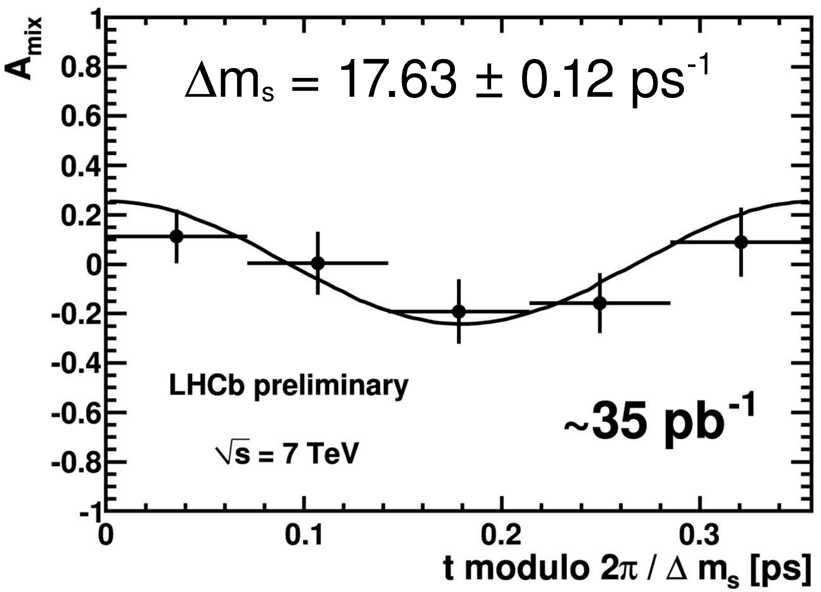
uncertainty ~ 13%

B_q-B_q mixing

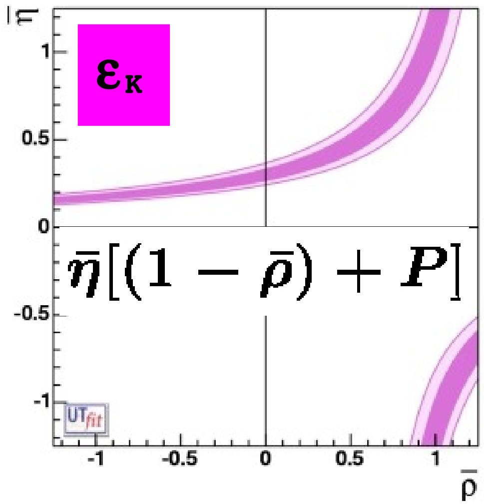
- Δm_d=(0.507 ± 0.005) ps^{-1}
- Δm_s=(17.70 ± 0.08) ps^{-1}

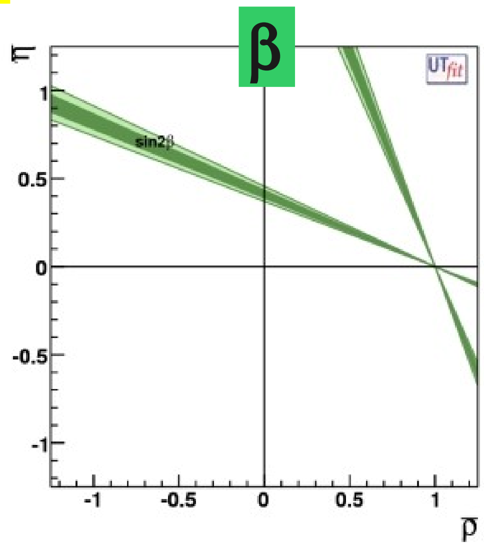
New world average from CDF and LHCb

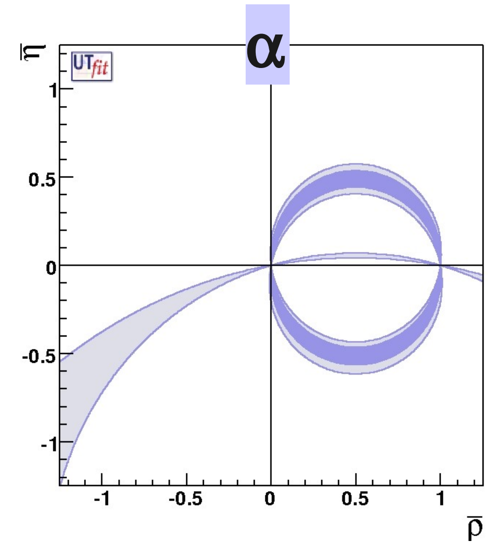




CP-violating inputs







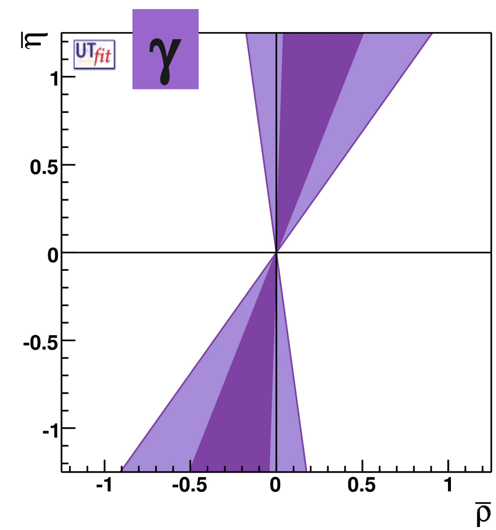
ε_K from K-K mixing

– $B_K = 0.731 \pm 0.036$

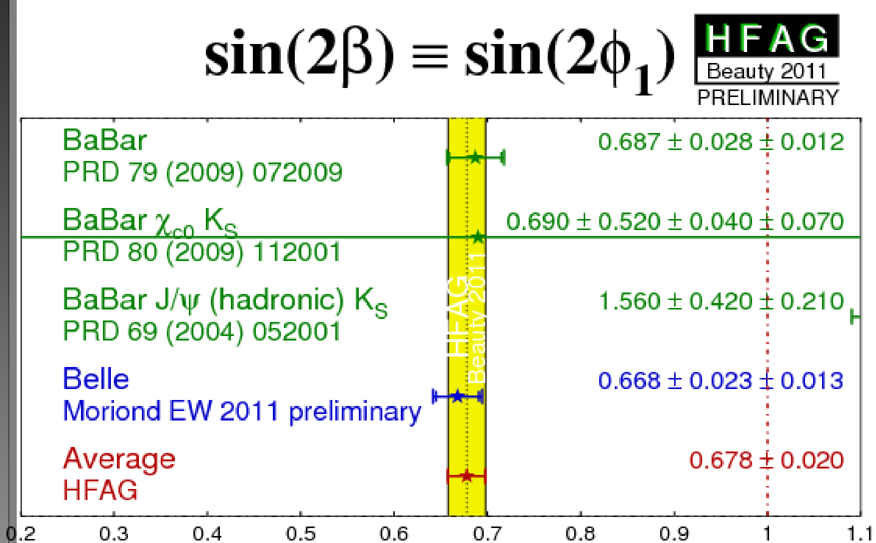
sin2β from $B \to J/\psi K^0$ + theory

α from ππ, ρρ, πρ decays:
combined: $(91 \pm 6)^o$

γ from $B \to DK$ decays (tree level)



Latest sin2β results:



BABAR Collaboration
Physical Review D 79:072009, 2009

BaBar with 465 10^6 $\bar{B}B$ pairs

$\sin 2\beta = 0.666 \pm 0.031 \pm 0.013$

Belle with 772 10^6 $\bar{B}B$ pairs

$\sin 2\beta = 0.663 \pm 0.025 \pm 0.013$

Belle Collaboration
Moriond EW 2011, preliminary

UTfit input value

$\sin 2\beta(J/\psi K^0) = 0.664 \pm 0.022$

EPS2011 update from Belle:

$\sin 2\beta(J/\psi K^0) = 0.668 \pm 0.026$

so new average should be

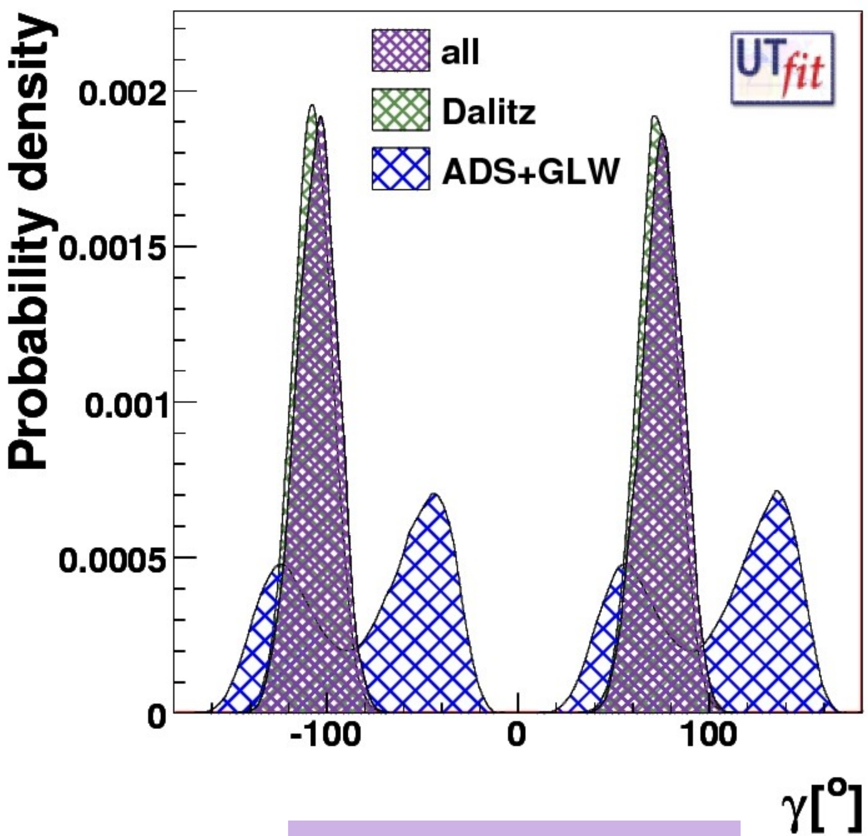
$\sin 2\beta(J/\psi K^0) = 0.667 \pm 0.021$

data-driven theoretical uncertainty

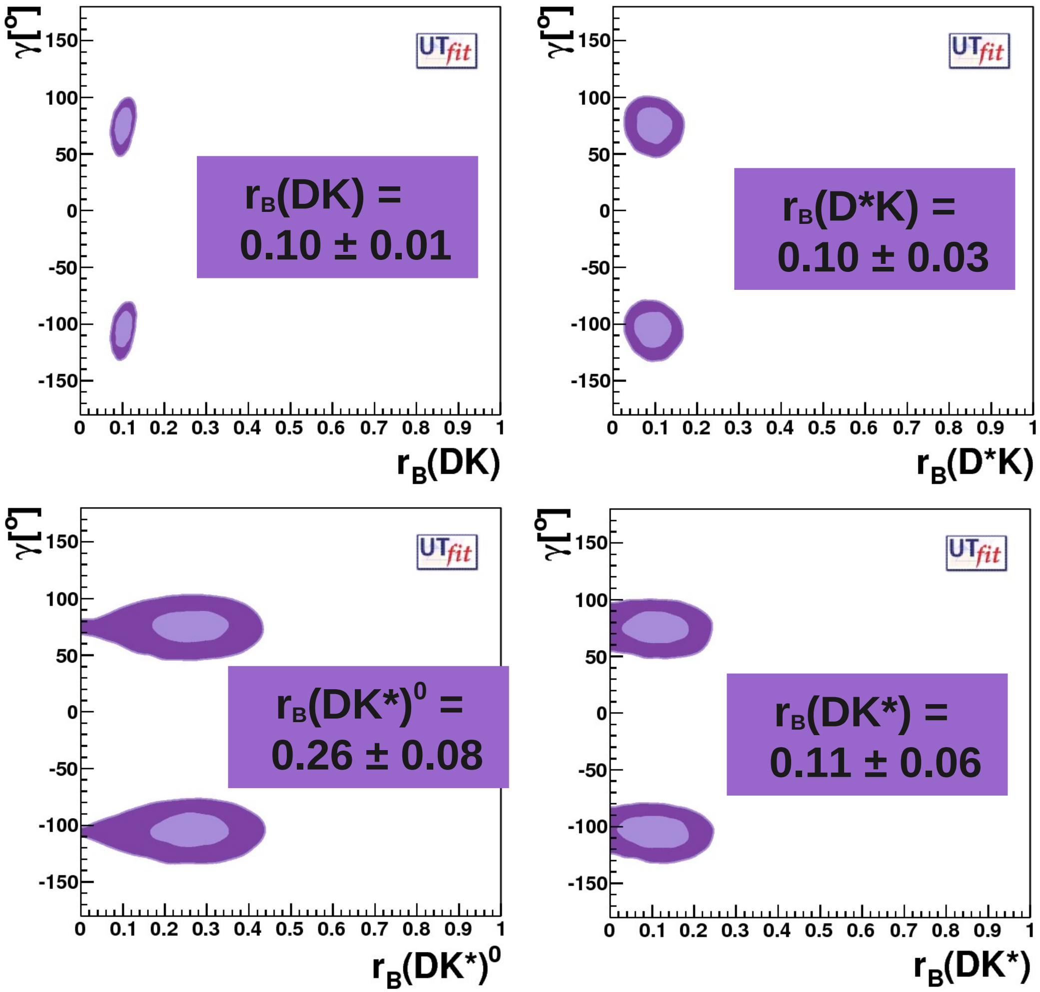
$\Delta S = 0.000 \pm 0.012$

M.Ciuchini, M.Pierini, L.Silvestrini
Phys. Rev. Lett. 95, 221804 (2005)

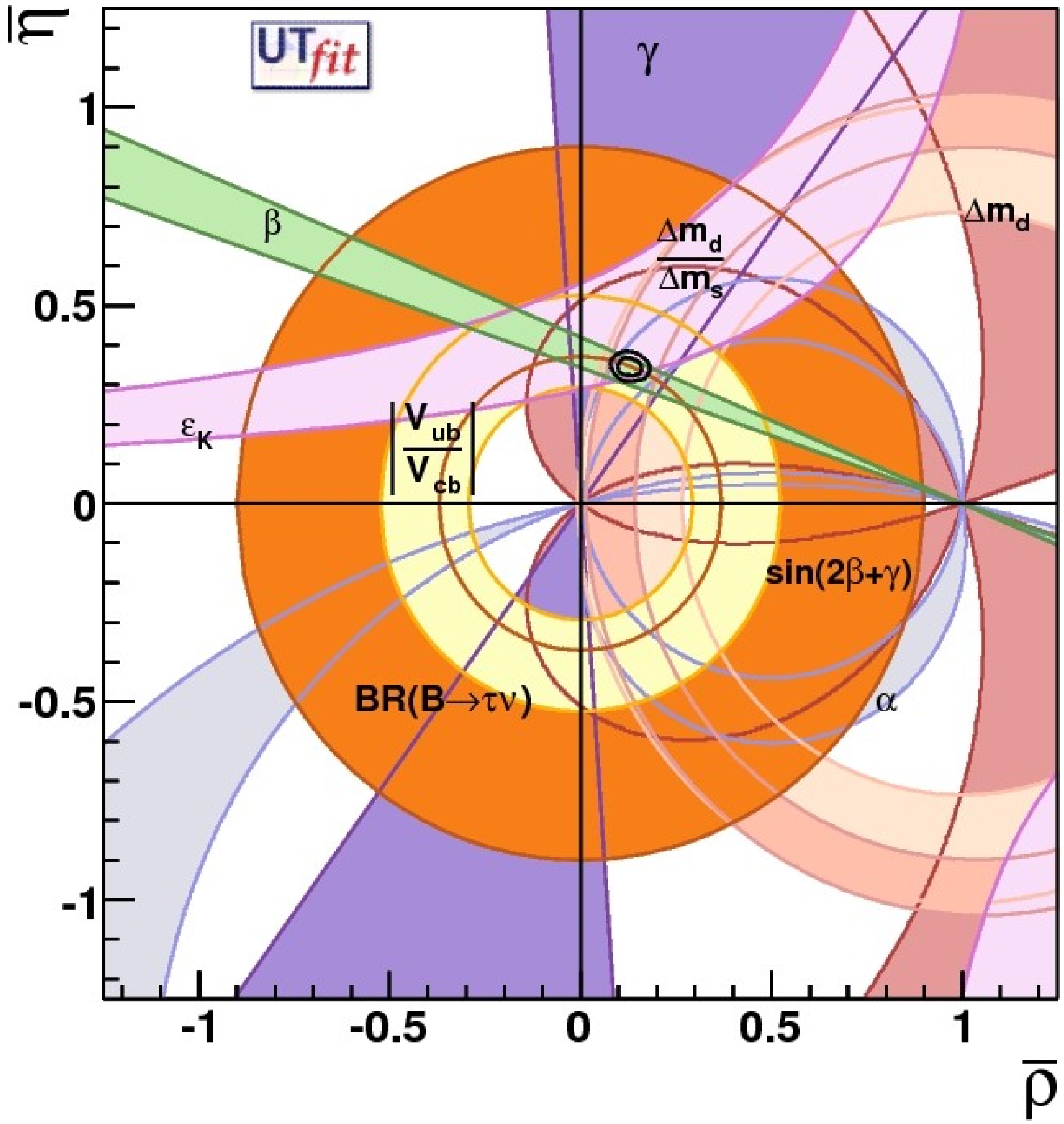
γ and DK trees



$\gamma = (76 \pm 11)^o$



unitarity Triangle analysis in the SM



levels @
95% Prob

$\bar{\rho} = 0.129 \pm 0.022$

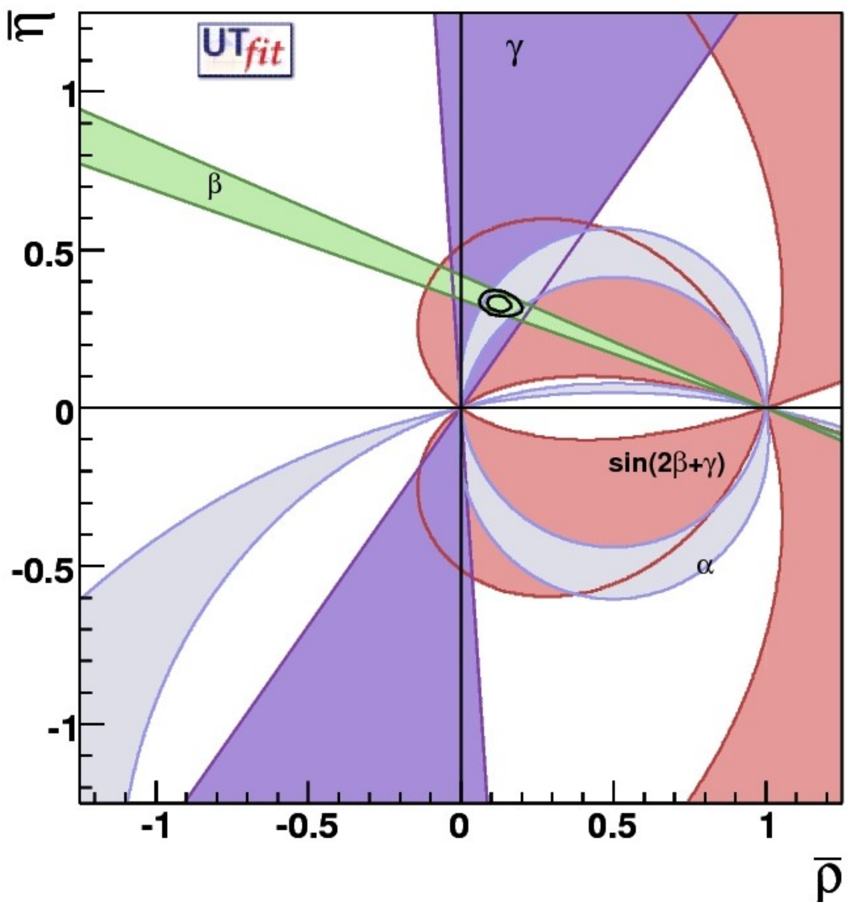
$\bar{\eta} = 0.346 \pm 0.015$

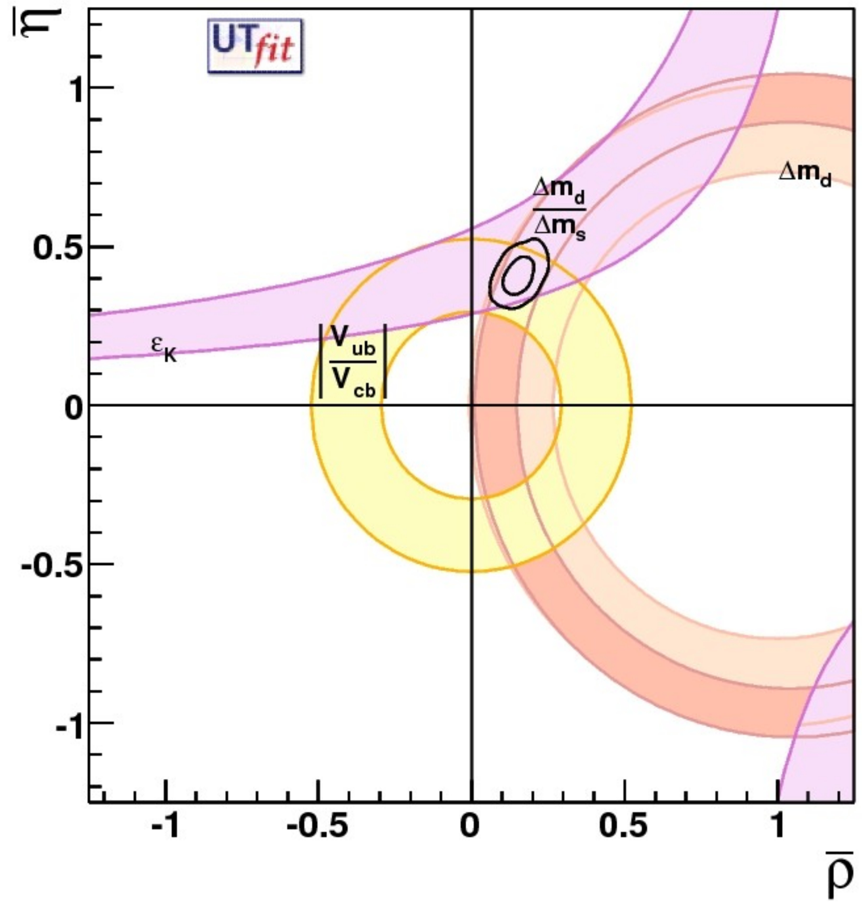
$\beta = (22 \pm 1)^\circ$

$\gamma = (69 \pm 3)^\circ$

$\alpha = (89 \pm 3)^\circ$

angles vs the others





$\bar{\rho} = 0.127 \pm 0.027$
$\bar{\eta} = 0.329 \pm 0.016$

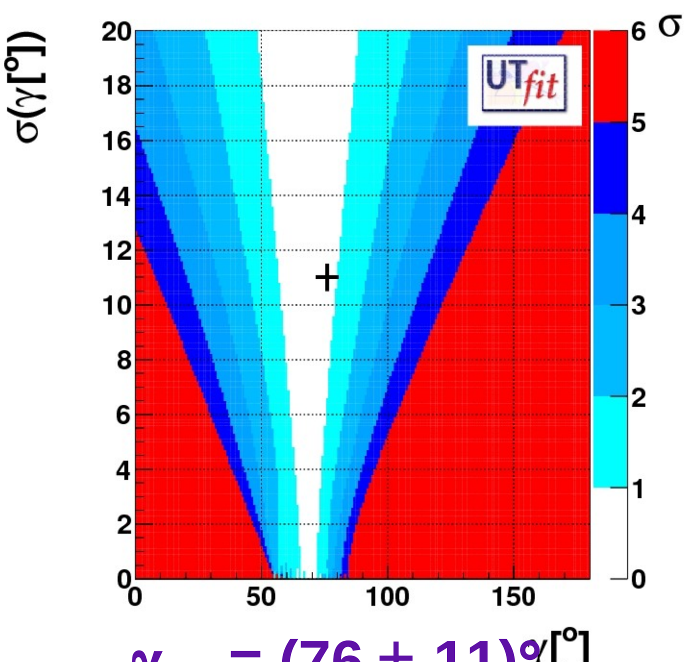
$\bar{\rho} = 0.157 \pm 0.037$
$\bar{\eta} = 0.409 \pm 0.043$

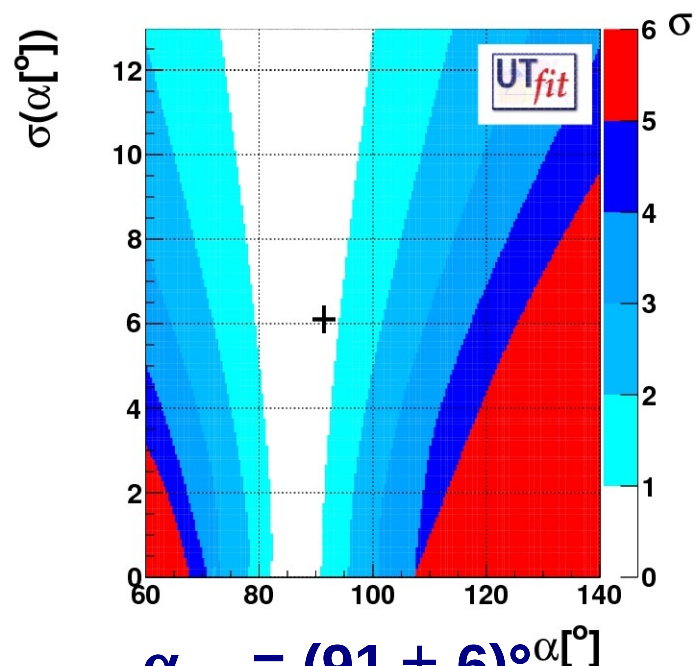
compatibility plots

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 flavor 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





$\gamma_{exp} = (76 \pm 11)°$

$\gamma_{UTfit} = (69 \pm 3)°$

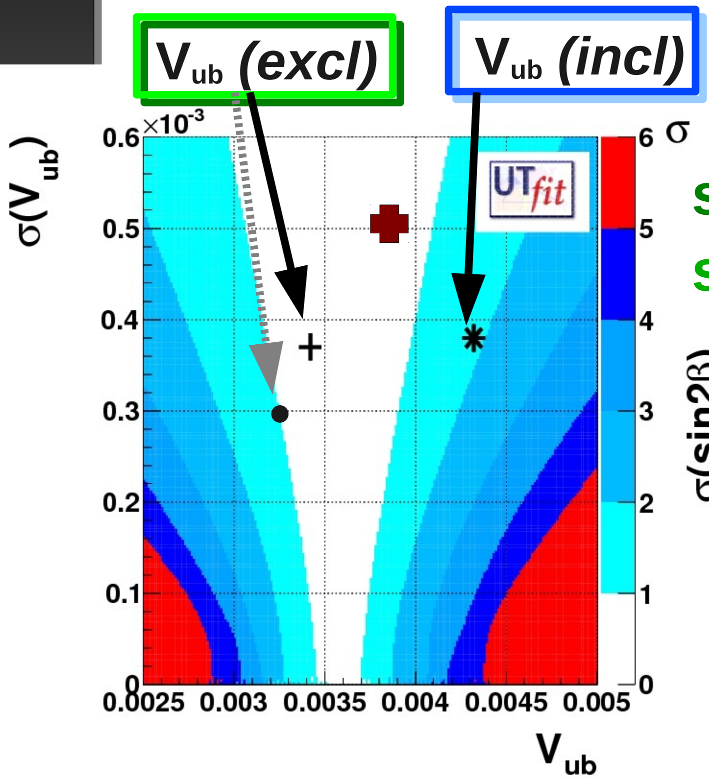
<1σ

$\alpha_{exp} = (91 \pm 6)°$

$\alpha_{UTfit} = (86 \pm 4)°$

<1σ

tensions



$Vub_{exp} = (3.86 \pm 0.52) \cdot 10^{-3}$

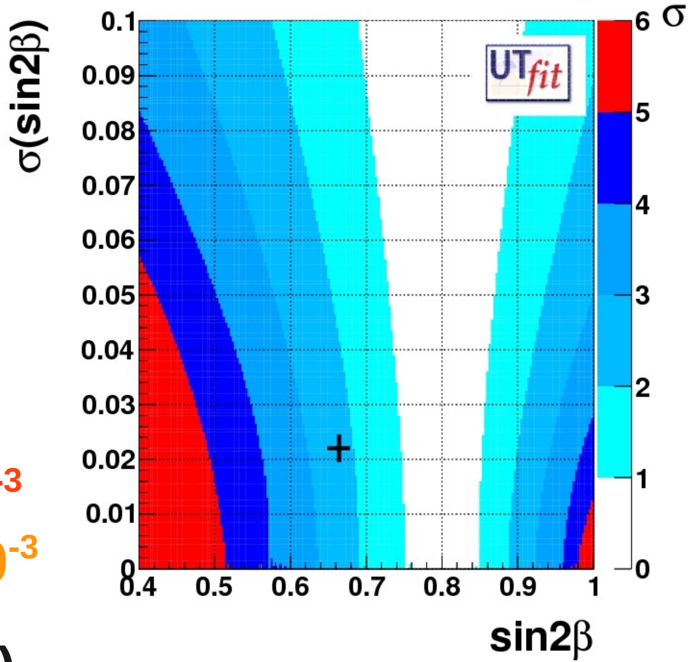
$Vub_{UTfit} = (3.57 \pm 0.14) \cdot 10^{-3}$

<1σ (incl ~1.8σ)

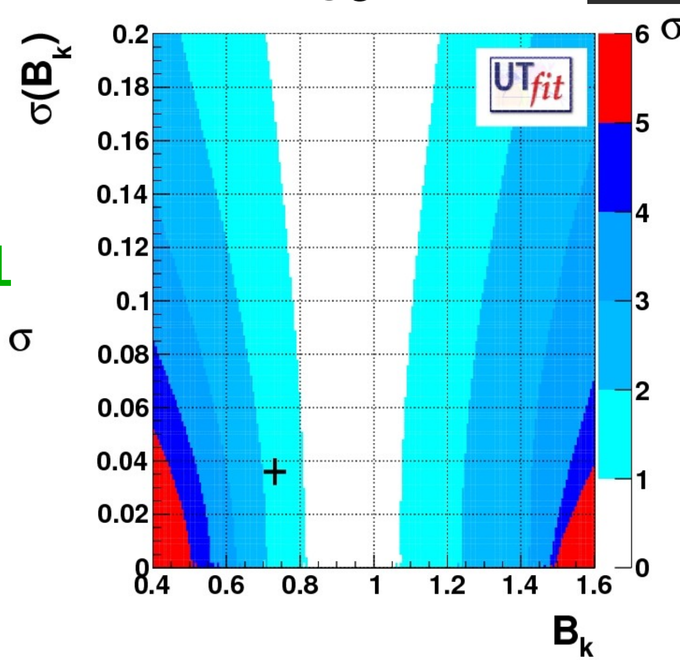
~2.3σ

$\sin 2\beta_{exp} = 0.664 \pm 0.022$

$\sin 2\beta_{UTfit} = 0.803 \pm 0.051$



~1.5σ

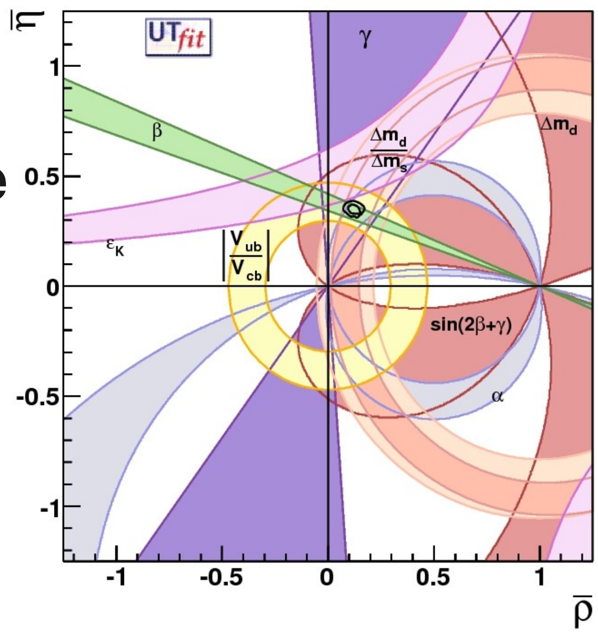


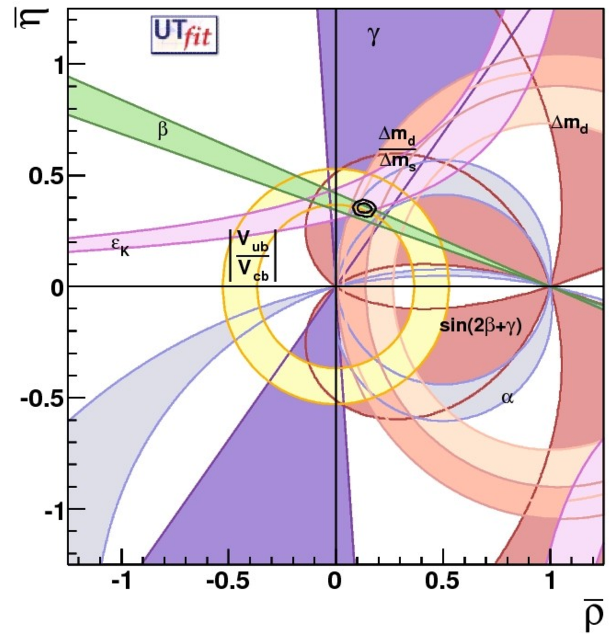
$BK_{exp} = 0.731 \pm 0.036$

$BK_{UTfit} = 0.93 \pm 0.13$

$BK_{nolattice} = 0.85 \pm 0.14$

only exclusive values

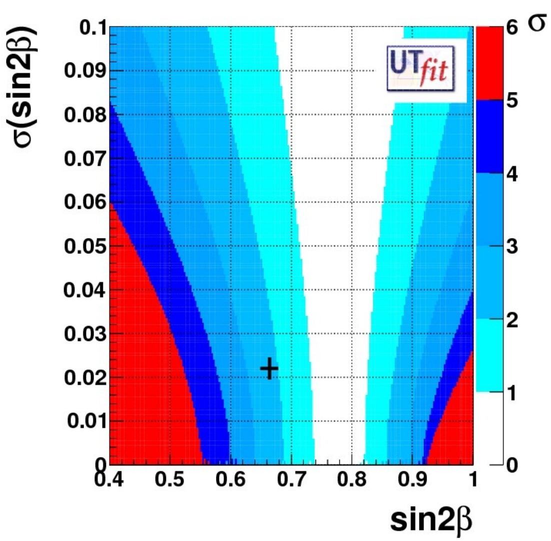


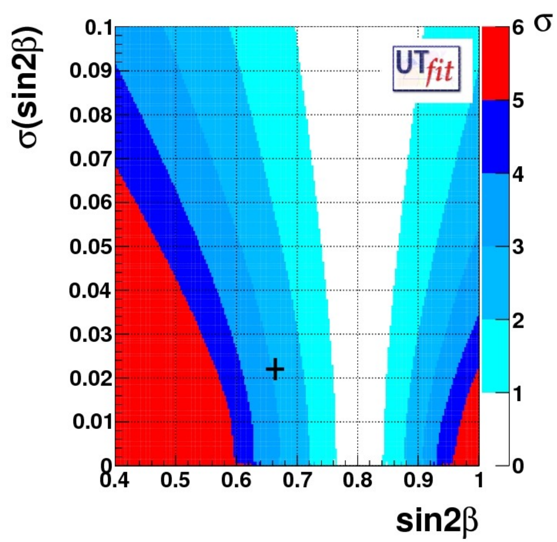


only inclusive values

$\sin 2\beta_{UTfit}$ = 0.783 ± 0.043

~2.3σ





$\sin 2\beta_{UTfit}$ = 0.804 ± 0.040

~2.9σ

$\sin 2\beta_{UTfit}$ = 0.846 ± 0.062 ¬ ***no semileptonic***

~2.4σ

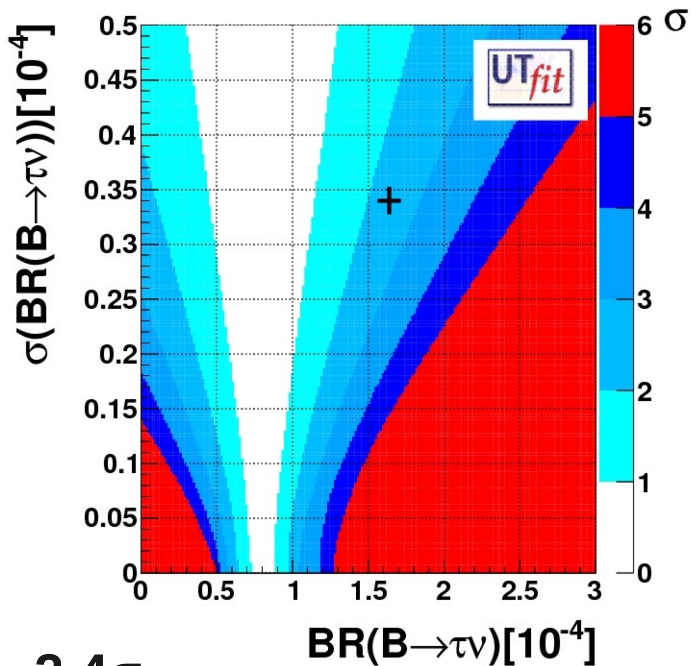
more standard model predictions:

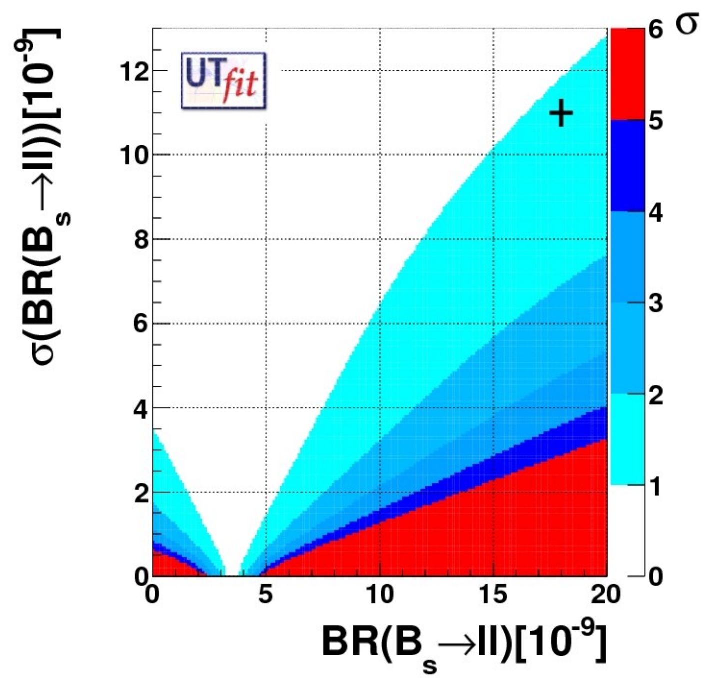
current HFAG world average

$BR(B\to\tau\nu) = (1.64 \pm 0.34)\ 10^{-4}$

latest CDF result

$BR(B_s\to\mu\mu) = (18^{+11}_{-9})\ 10^{-9}$





~2.4σ

indirect determinations from UT

$BR(B\to\tau\nu) = (0.79 \pm 0.08)\ 10^{-4}$

$BR(B_s\to ll) = (3.54 \pm 0.29)\ 10^{-9}$

M.Bona et al
0908.3470 [hep-ph]

UTfit beyond the MFV:

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

D0
Phys.Rev.D82:012003,2010

semileptonic asymmetry:
sensitive to NP effects in both size and phase

$$A^{s}_{\mathrm{SL}} \times 10^{2} = -0.17 \pm 0.91$$

same-side dilepton charge asymmetry:
admixture of B_s and B_d so sensitive to NP effects in both systems

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

D0 arXiv:1106.6308

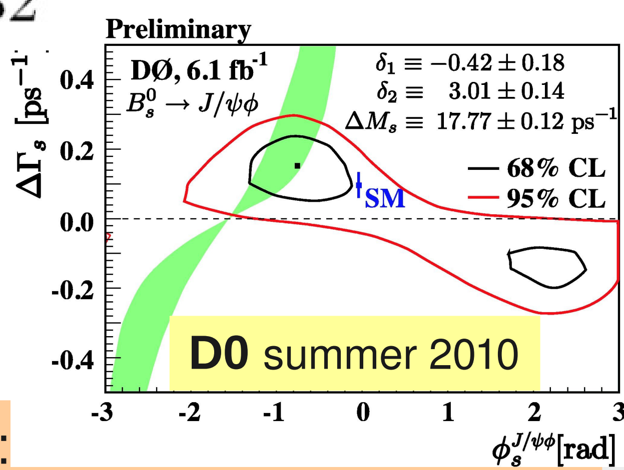
lifetime τ^{FS} in flavour-specific final states:
average lifetime is a function to the width and the width difference (independent data sample)

HFAG

$$\tau^{\mathrm{FS}}_{B_s}\ [\mathrm{ps}] = 1.461 \pm 0.032$$

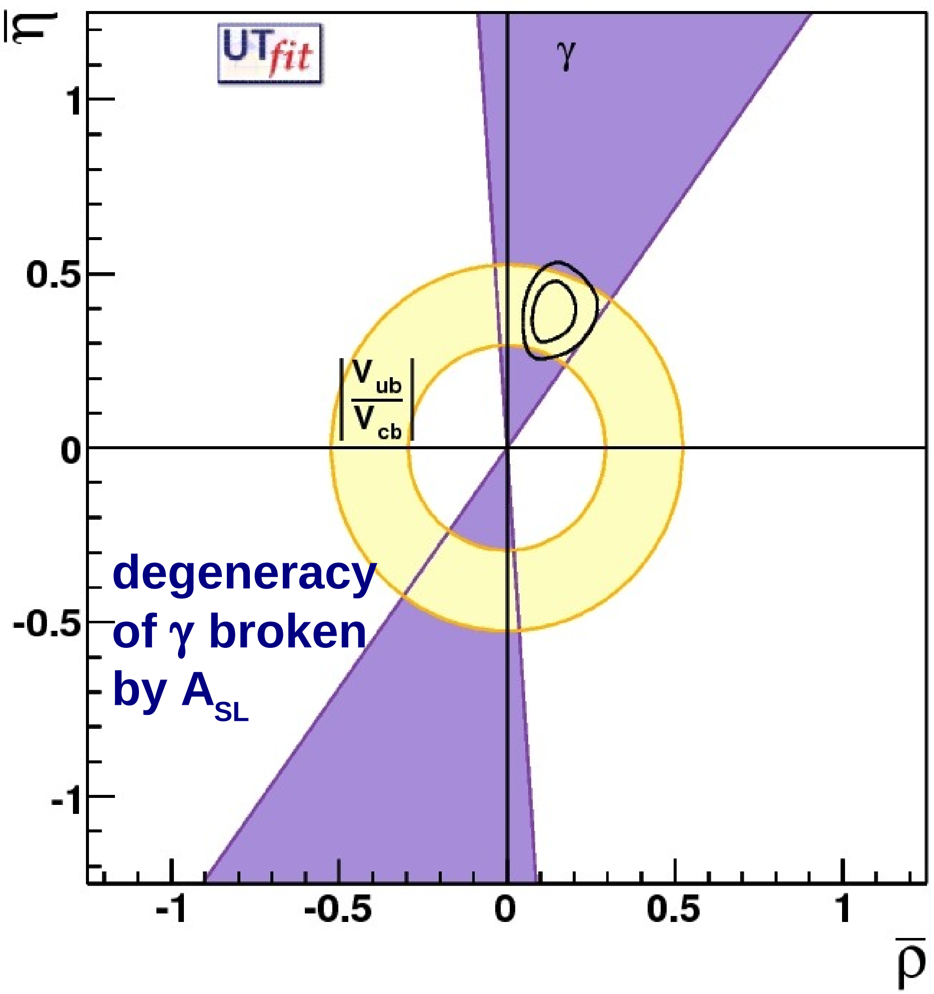
$\phi_s=2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$

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



ϕ_s and $\Delta\Gamma_s$:
2D experimental likelihood from D0

NP analysis results



$\bar{\rho} = 0.145 \pm 0.045$
$\bar{\eta} = 0.389 \pm 0.054$

SM is

$\bar{\rho} = 0.129 \pm 0.022$
$\bar{\eta} = 0.346 \pm 0.015$

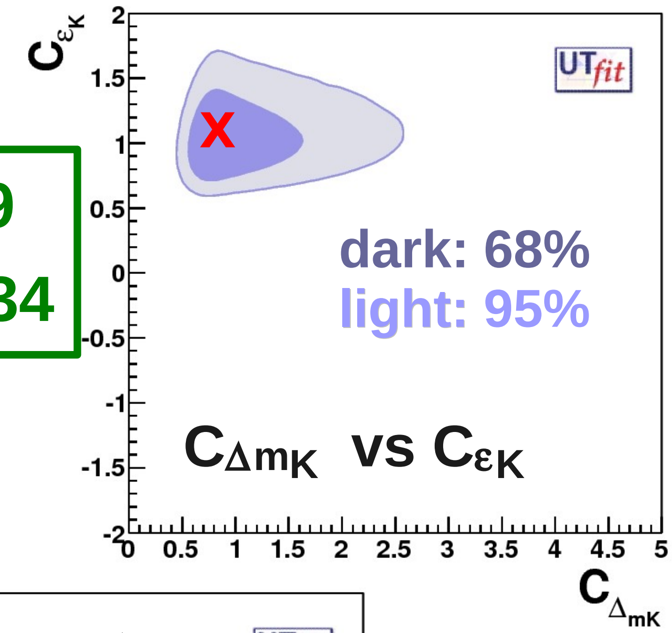
NP parameter results

$C_{\varepsilon_K} = 1.02 \pm 0.19$

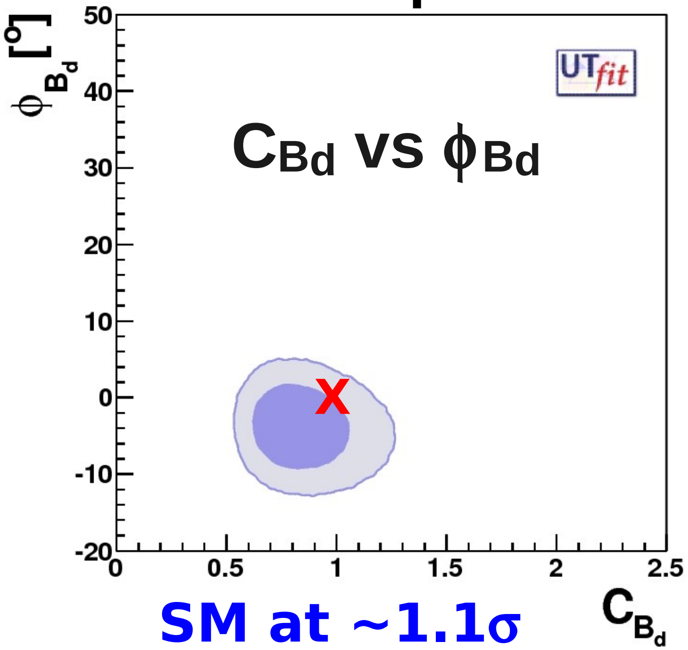
$C_{\Delta m_K} = 0.96 \pm 0.34$

$C_{B_d} = 0.82 \pm 0.14$

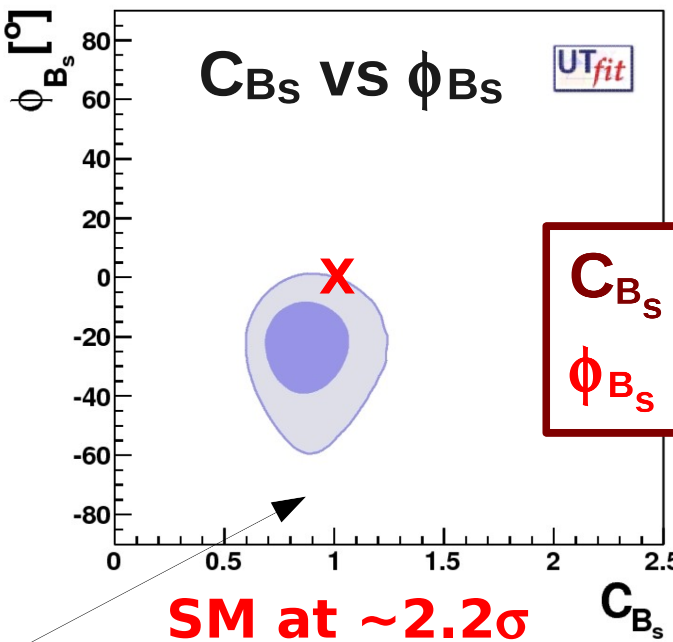
$\phi_{B_d} = (-3.9 \pm 3.6)°$



X SM expectation



SM at ~1.1σ



$C_{B_s} = 0.87 \pm 0.12$

$\phi_{B_s} = (-23 \pm 10)°$

SM at ~2.2σ

one ambiguity missing as D0 uses the sign of $B_d \to J/\psi K^*$ strong phase to eliminate it

conclusions

- **SM analysis displays good overall consistency but some tension in sin2β, B_k and $B \to \tau\nu$**
- **Extraction of SM predictions with different scenarios: semileptonic inclusive vs exclusive**
- **The tensions pull $|V_{ub}|$ in opposite directions**
- **General UTA provides a precise determination of CKM parameters and NP contributions to $\Delta F=2$ amplitudes**

we would love to use the results from all the collaborations: please release the likelihood!

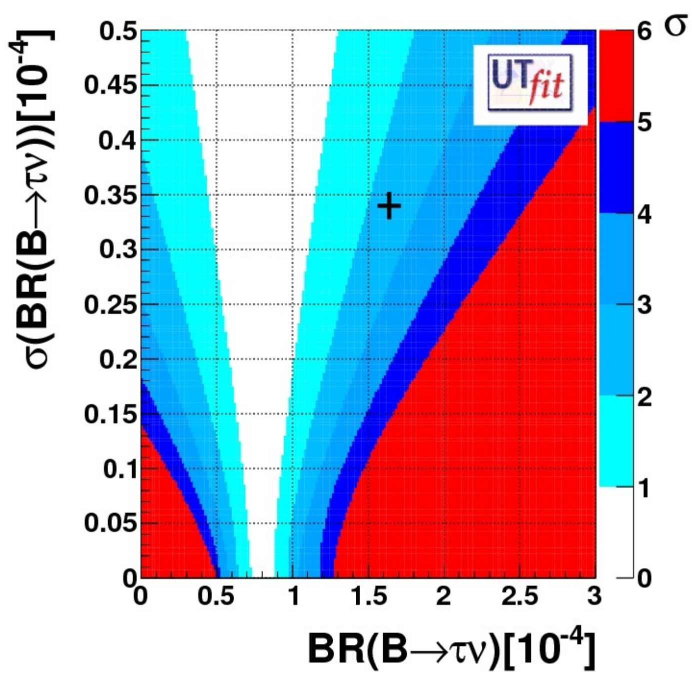

AAUGH!

backup

more standard model determinations: $B_d \to \tau\nu$

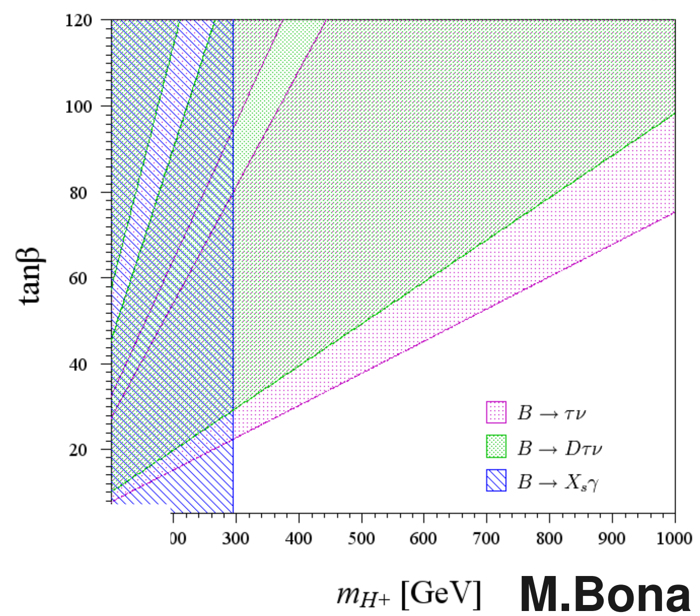
current HFAG world average
$BR(B\to\tau\nu) = (1.64 \pm 0.34)\ 10^{-4}$

$$\mathcal{B}(B \to \ell\nu) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$



SM prediction enhanced or reduced by factor r_H:

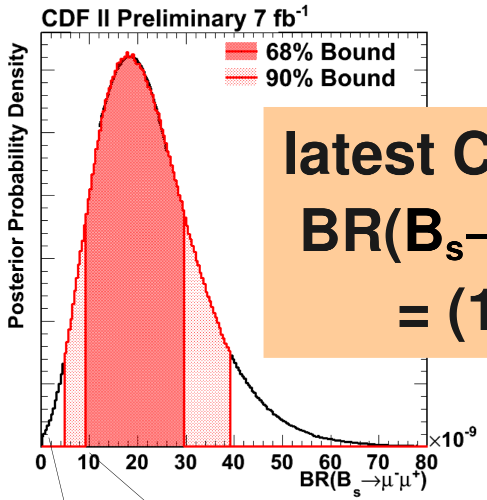
$$R_{2HDM} = \left(1 - \tan^2\beta \frac{m_B^2}{m_{H^+}^2}\right)^2$$



indirect determination from UT_b
$BR(B\to\tau\nu) = (0.79 \pm 0.08)\ 10^{-4}$

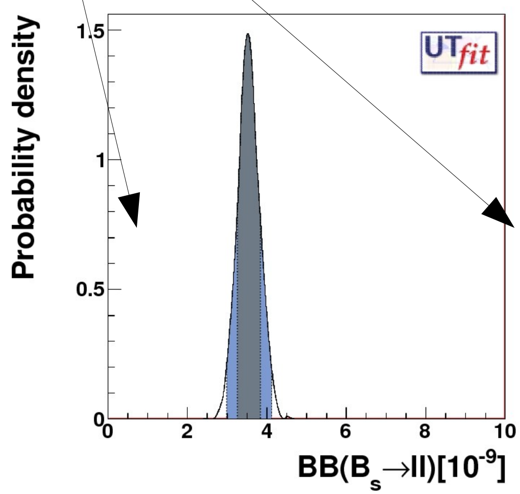
M.Bona et al 0908.3470 [hep-ph]

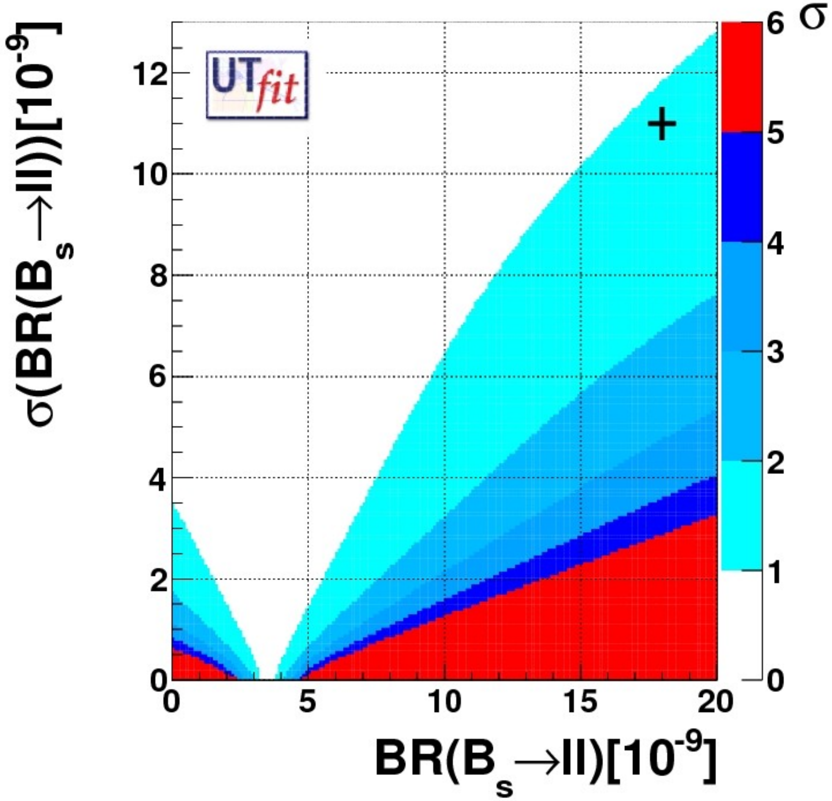
more standard model determinations: $B_s \to \mu\mu$



latest CDF result:

$BR(B_s \to \mu\mu) = (18^{+11}_{-9})\ 10^{-9}$

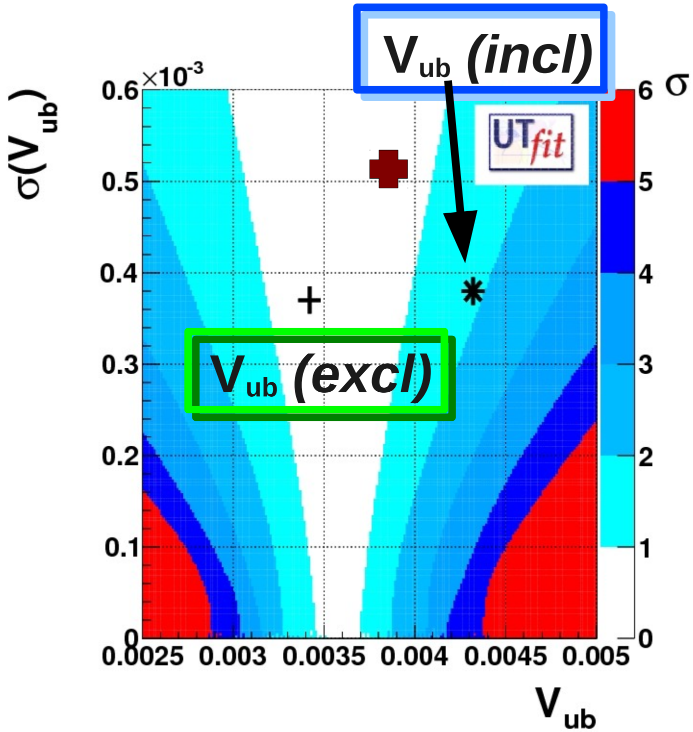




indirect determination from UT

$BR(B_s \to ll) = (3.54 \pm 0.29)\ 10^{-9}$

tensions

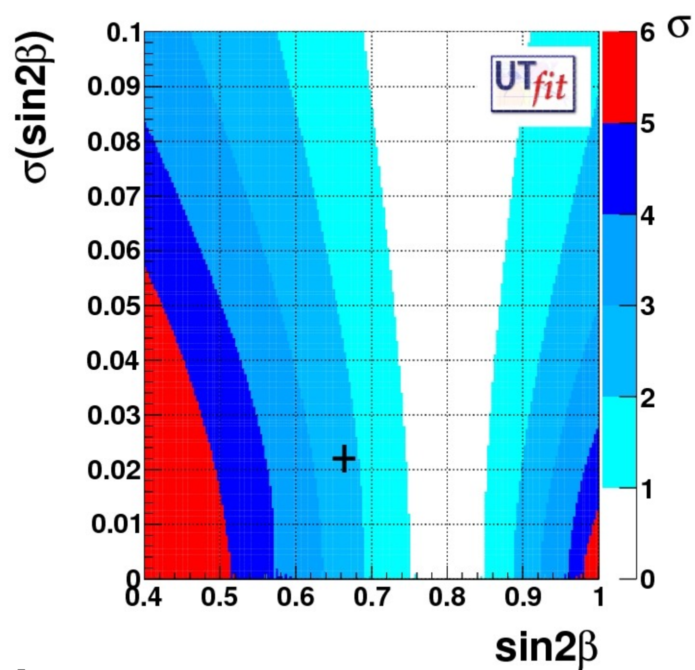


Vub_{exp} = (3.86 ± 0.52) · 10^{-3}
Vub_{UTfit} = (3.57 ± 0.14) · 10^{-3}

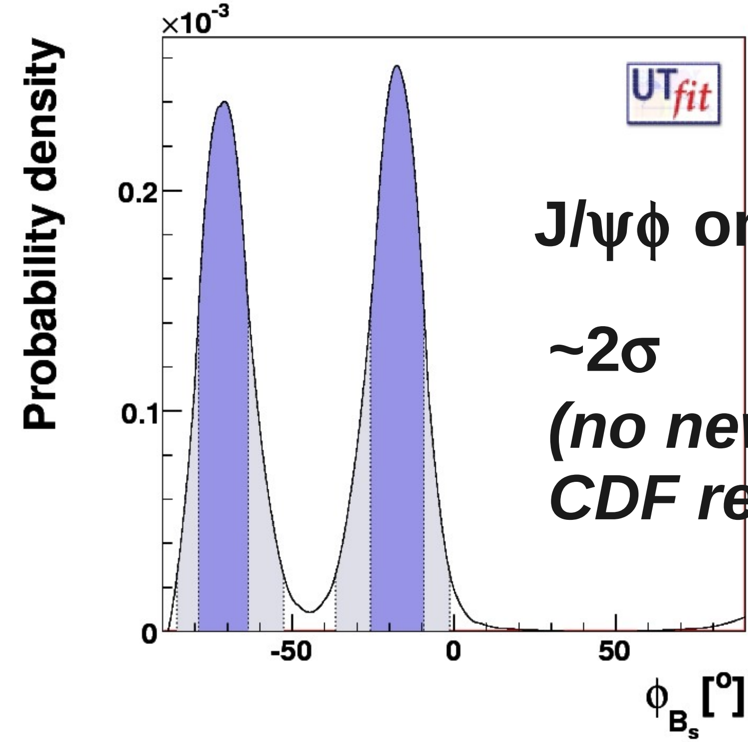
<1σ (incl ~1.8σ)

~2.3σ

$\sin 2\beta_{exp}$ = 0.664 ± 0.022
$\sin 2\beta_{UTfit}$ = 0.803 ± 0.051

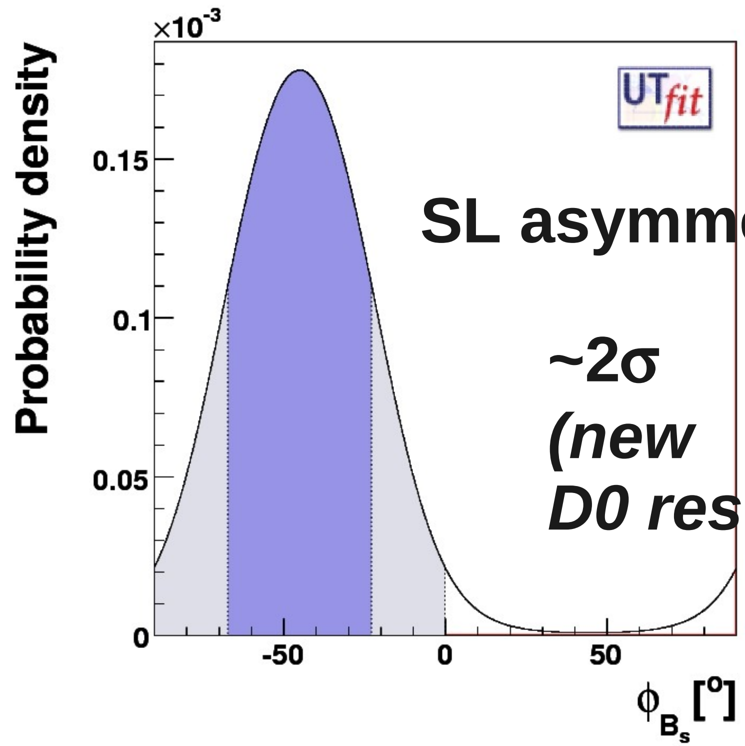


B_s NP phase



J/ψϕ only

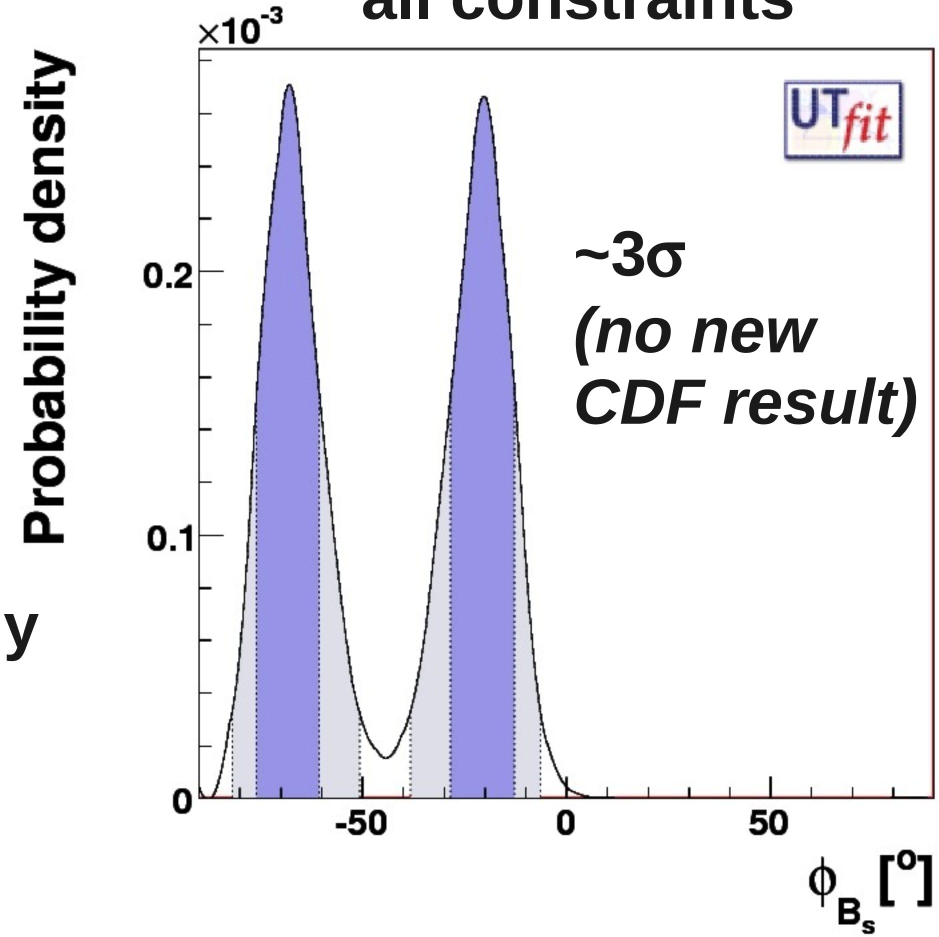
~2σ
(no new CDF result)



SL asymmetries only

~2σ
(new D0 result)

all constraints

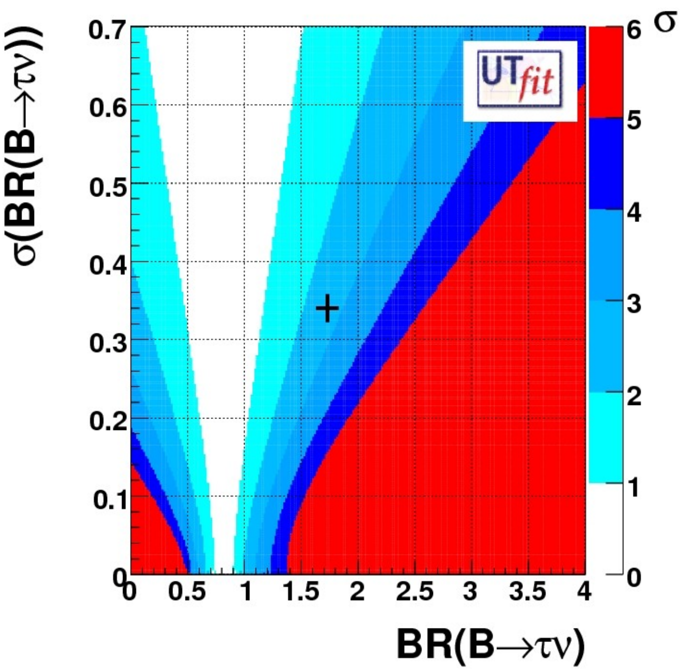


~3σ
(no new CDF result)

$B\to\tau\nu$

M. Bona *et al.* (UTfit) Phys.Lett.B 687, 61 (2010)

Unitarity Triangle fit



Consider MFV models

Define a Universal Unitarity Triangle using only observables unaffected by MFV-NP: R_b & angles

Define $\overline{BR}$ as the prediction obtained assuming NO NP effect in the decay amplitude

$BR(B\to\tau\nu)_{exp} = (1.74 \pm 0.34)\cdot 10^{-4}$

$BR(B\to\tau\nu)_{UTfit} = (0.79 \pm 0.07)\cdot 10^{-4}$

$\sim 2.7\sigma$

$R^{exp}_{UUT} = 2.1 \pm 0.5$

where

$R^{exp}_{UUT} = BR_{exp} / \overline{BR}_{UUT}$

to be compared with the $|V_{ub}|$- and f_B-independent theory calculation of R_{UUT} in specific MFV models

M. Bona *et al.* (UTfit) Phys.Lett.B 687, 61 (2010)

Consider Two Higgs Doublet model II

$$R_{2\mathrm{HDM}} = \left(1 - \tan^2\beta \frac{m_B^2}{m_{H+}^2}\right)^2$$

→ **bounds on tanβ/m_{H+}**

Two regions selected:

1. **small tanβ/m_{H+}: R < 1 disfavoured at ~2σ**
2. **"fine-tuned" region for tanβ/m_{H+} ~ 0.3:**
   positive correction, R ~ R_{exp} can be obtained

incompatible with semileptonic decays
BR(B→Dτν)/BR(B→Dℓν) = (49±10)%

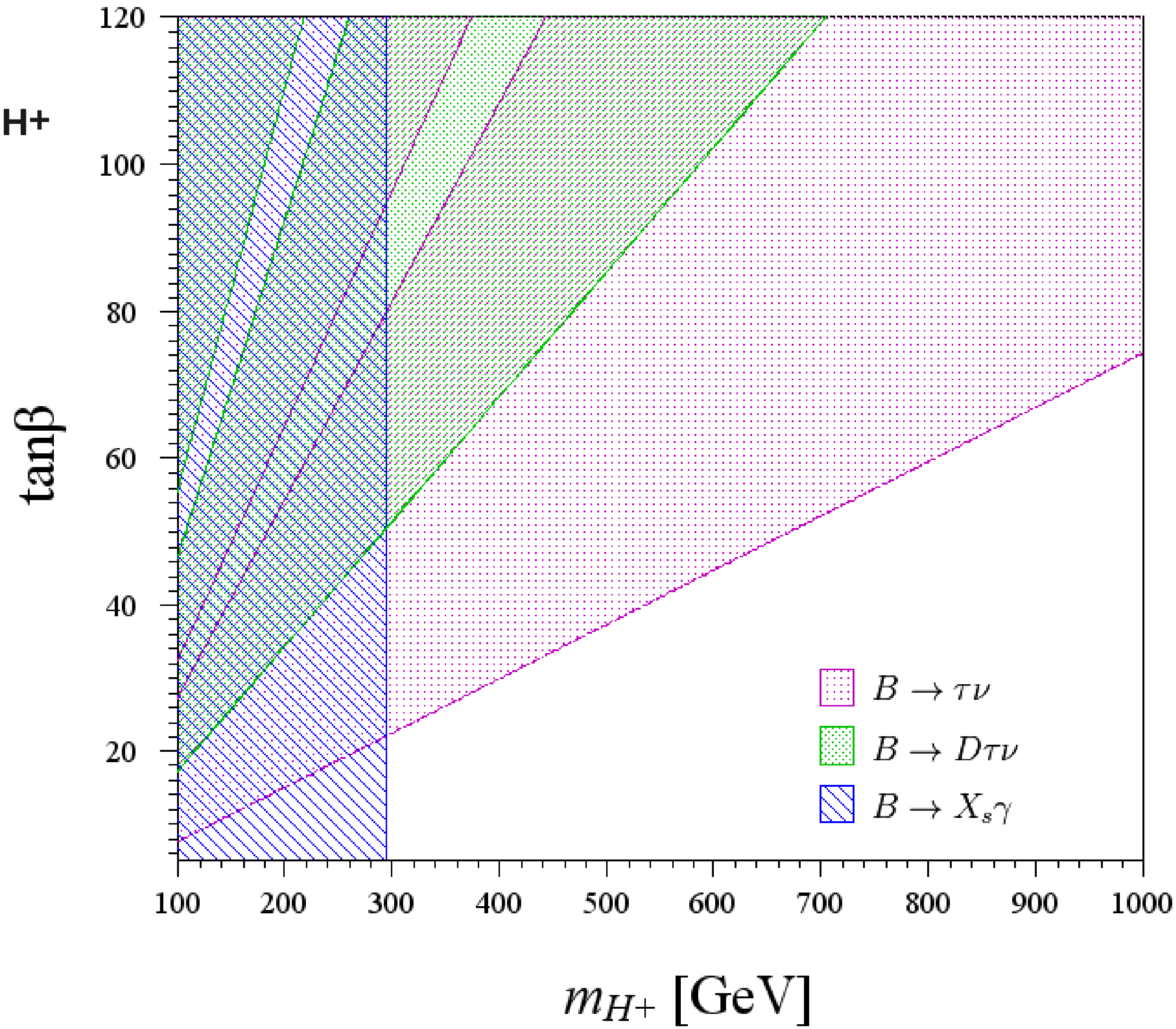
B→ $X_s\gamma$ gives a lower bound on m_{H+}:
m_{H+}>295 GeV

M. Bona *et al.* (UTfit)
Unitarity Triangle fit
Phys.Lett.B 687, 61 (2010)

Consider Two Higgs Doublet model II

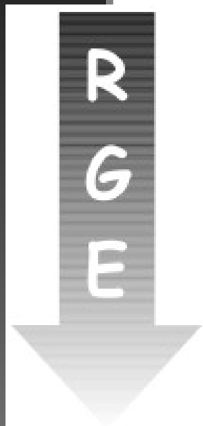
$$R_{2\mathrm{HDM}} = \left(1 - \tan^2\beta \frac{m_B^2}{m_{H^+}^2}\right)^2$$

→ **bounds on tanβ/m$_{H+}$**



$$\tan\beta < 7.4 \frac{m_{H^+}}{100\ \mathrm{GeV}}$$

Testing the new-physics scale



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

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

$$Q_1^{q_i q_j} = \bar{q}^{\alpha}_{jL}\gamma_\mu q^{\alpha}_{iL}\bar{q}^{\beta}_{jL}\gamma^\mu q^{\beta}_{iL} ,$$

$$Q_2^{q_i q_j} = \bar{q}^{\alpha}_{jR} q^{\alpha}_{iL}\bar{q}^{\beta}_{jR} q^{\beta}_{iL} ,$$

$$Q_3^{q_i q_j} = \bar{q}^{\alpha}_{jR} q^{\beta}_{iL}\bar{q}^{\beta}_{jR} q^{\alpha}_{iL} ,$$

$$Q_4^{q_i q_j} = \bar{q}^{\alpha}_{jR} q^{\alpha}_{iL}\bar{q}^{\beta}_{jL} q^{\beta}_{iR} ,$$

$$Q_5^{q_i q_j} = \bar{q}^{\alpha}_{jR} q^{\beta}_{iL}\bar{q}^{\beta}_{jL} q^{\alpha}_{iR} .$$

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

Most general form of the effective Hamiltonian for ΔF=2 processes

$$\mathcal{H}_{\rm eff}^{K-\bar{K}} = \sum_{i=1}^{5} C_i\, Q_i^{sd} + \sum_{i=1}^{3} \tilde{C}_i\, \tilde{Q}_i^{sd}$$

$$\mathcal{H}_{\rm eff}^{B_q-\bar{B}_q} = \sum_{i=1}^{5} C_i\, Q_i^{bq} + \sum_{i=1}^{3} \tilde{C}_i\, \tilde{Q}_i^{bq}$$

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)

Contribution to the mixing amplitutes

analytic expression for the contribution to the mixing amplitudes

Lattice QCD

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

***arXiv:0707.0636:* *for "magic numbers" a,b and c*, η = $\alpha_s(\Lambda)/\alpha_s(m_t)$**

analogously for the K system

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

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.

Testing the TeV scale

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

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

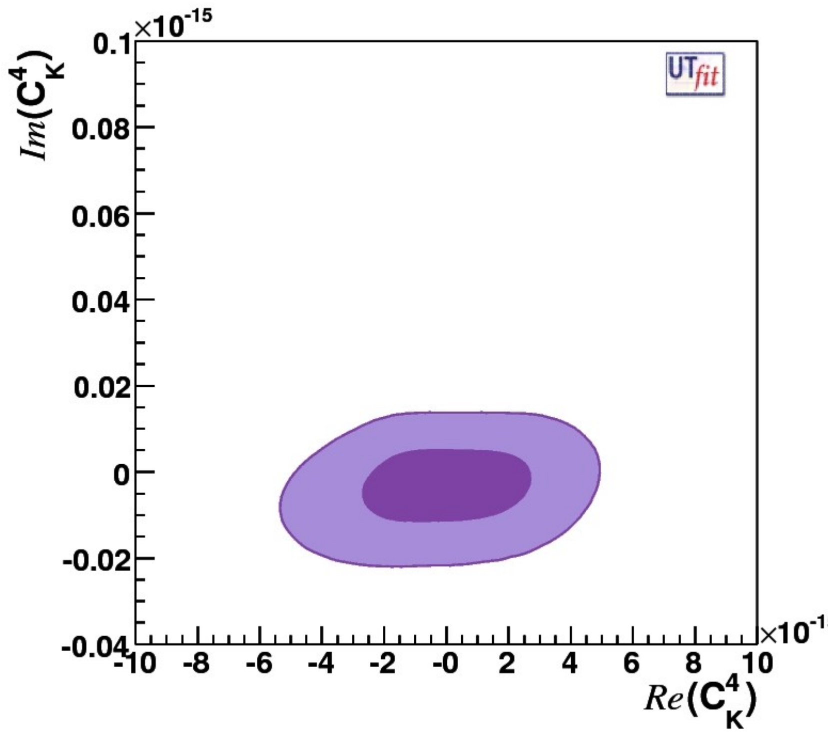
If no NP effect is seen
lower bound on NP scale Λ
if NP is seen
upper bound on NP scale Λ

F_{SM} is the combination of CKM factors for the considered process

Results from the Wilson coefficients

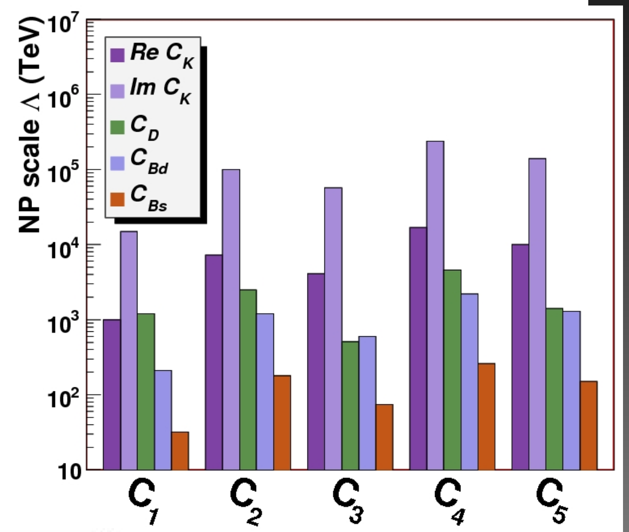
the results obtained for the flavour scenarios:
In deriving the lower bounds on the NP scale, we assume Li = 1, corresponding to strongly-interacting and/or tree-level NP.

Parameter	95% allowed range (GeV^{-2})	Lower limit on Λ (TeV) for arbitrary NP	Lower limit on Λ (TeV) for NMFV
$\text{Re}C_K^1$	$[-9.6, 9.6] \cdot 10^{-13}$	$1.0 \cdot 10^3$	0.35
$\text{Re}C_K^2$	$[-1.8, 1.9] \cdot 10^{-14}$	$7.3 \cdot 10^3$	2.0
$\text{Re}C_K^3$	$[-6.0, 5.6] \cdot 10^{-14}$	$4.1 \cdot 10^3$	1.1
$\text{Re}C_K^4$	$[-3.6, 3.6] \cdot 10^{-15}$	$17 \cdot 10^3$	4.0
$\text{Re}C_K^5$	$[-1.0, 1.0] \cdot 10^{-14}$	$10 \cdot 10^3$	2.4
$\text{Im}C_K^1$	$[-4.4, 2.8] \cdot 10^{-15}$	$1.5 \cdot 10^4$	5.6
$\text{Im}C_K^2$	$[-5.1, 9.3] \cdot 10^{-17}$	$10 \cdot 10^4$	28
$\text{Im}C_K^3$	$[-3.1, 1.7] \cdot 10^{-16}$	$5.7 \cdot 10^4$	19
$\text{Im}C_K^4$	$[-1.8, 0.9] \cdot 10^{-17}$	$24 \cdot 10^4$	62
$\text{Im}C_K^5$	$[-5.2, 2.8] \cdot 10^{-17}$	$14 \cdot 10^4$	37



To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by $\alpha_s \sim 0.1$ or by $\alpha_W \sim 0.03$.

Upper and lower bound on the scale



Lower bounds on NP scale from K and B_d physics (in TeV at 95% prob.)

Scenario	strong/tree	α_s loop	α_W loop
MFV	5.5	0.5	0.2
NMFV	62	6.2	2
General	24000	2400	800

Upper bounds on NP scale from B_s:

Scenario	strong/tree	α_s loop	α_W loop
NMFV	35	4	2
General	800	80	30

- **the general case was already problematic (well known flavour puzzle)**
- **NMFV has problems with the size of the B_s effect vs the (insufficient) suppression in B_d and (in particular) K mixing**
- **MFV is OK for the size of the effects, but the B_s phase cannot be generated**

Data suggest some hierarchy in NP mixing which is stronger than the SM one