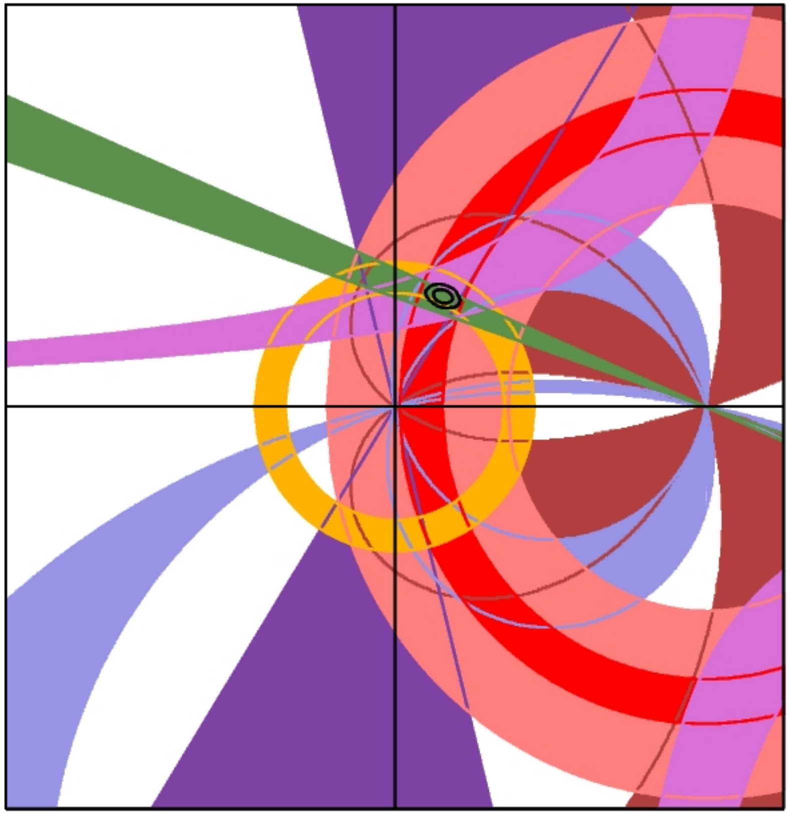
Standard Model updates and new physics analysis with the Unitarity Triangle fit



Marcella Bona

Queen Mary
University of London

FPCP 2010,
Torino, Italy
May 28th, 2010

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

UTfit

www.utfit.org

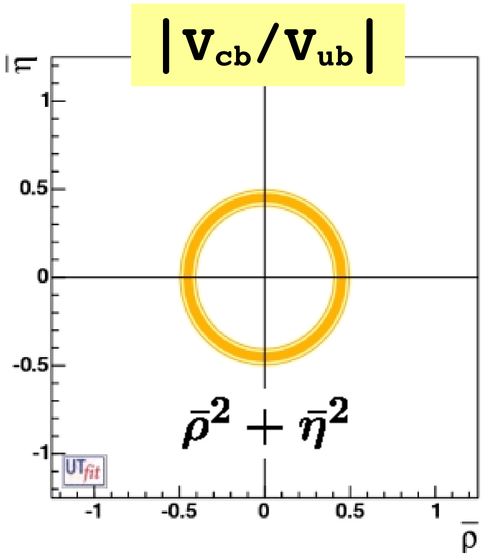
A. Bevan, M. Bona, M. Ciuchini,
D. Derkach, E. Franco, V. Lubicz,
G. Martinelli, F. Parodi, M. Pierini,
C. Schiavi, L. Silvestrini, A. Stocchi,
V. Sordini, C. Tarantino and V. Vagnoni

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 future experiments (ex. $\sin 2\beta$, Δm_s, …)

CP-conserving inputs



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

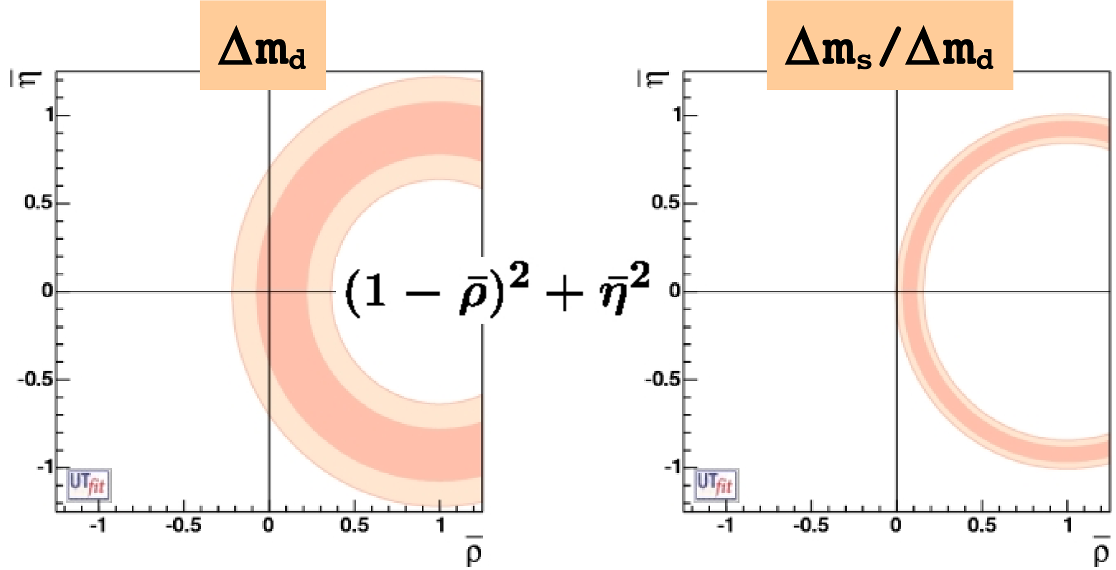
- inclusive:
  - $b \to c l \nu \Rightarrow |V_{cb}|=(41.54 \pm 0.44 \pm 0.58) 10^{-3}$
  - $b \to u l \nu \Rightarrow |V_{ub}|=(39.9 \pm 1.5 \pm 4.0)\ 10^{-4}$

    (HFAG + flat error for model spread)
- exclusive:
  - $B \to D^{(*)} l \nu \Rightarrow |V_{cb}|=(39.0 \pm 0.9) 10^{-3}$
  - $b \to \pi(\rho) l \nu \Rightarrow |V_{ub}|=(35.0 \pm 4.0)\ 10^{-4}$

    using LQCD form factors

Lubicz & Tarantino

CP-conserving inputs

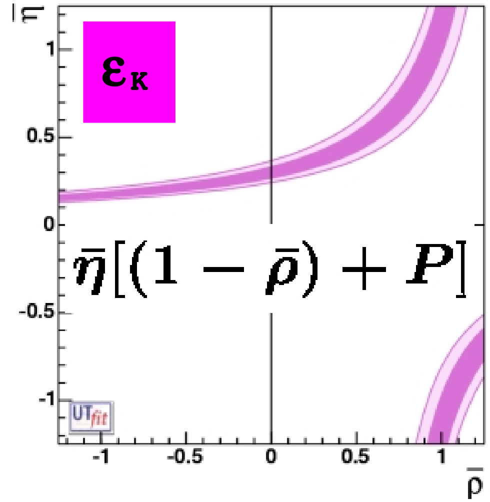


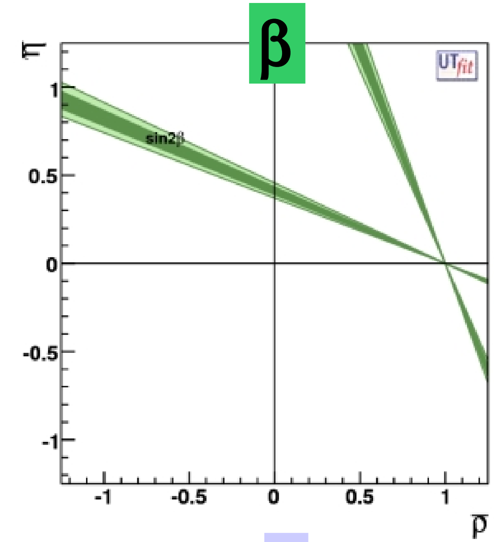
$|V_{td}|/|V_{cb}| \sim R_t$ from B_d-B_d and B_s-B_s mixing (loop mediated):

- $\Delta m_d = (0.507 \pm 0.005)\ \mathrm{ps}^{-1}$
- $\Delta m_s = (17.77 \pm 0.12)\ \mathrm{ps}^{-1}$
- $f_{Bs}\sqrt{B_{Bs}} = (275 \pm 13)$ MeV
- $\xi = 1.24 \pm 0.03$

Laiho, Lunghi, V.d.Water

CP-violating inputs





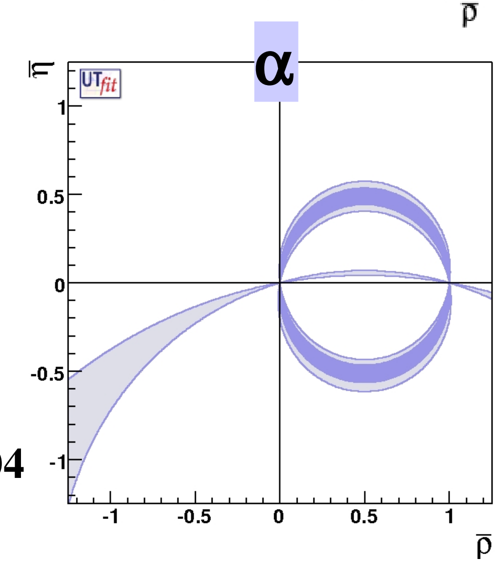
Buras, Guadagnoli, Isidori

ε_K corrected for measured phase, Im A_0 and LD contributions

– F_K = 156.0 ± 1.3 MeV

– B_K = 0.731 ± 0.036

Lubicz @ Lattice09

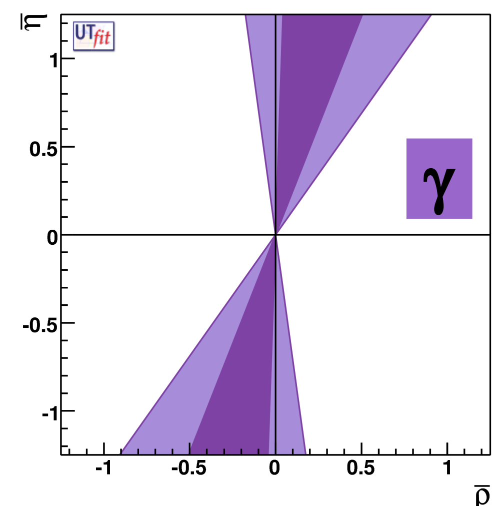


Phys.Rev.Lett. 95 (2005) 221804

Sin2β from B → J/ψK + theory error from CPS: sin2β = 0.655 ± 0.024 HFAG

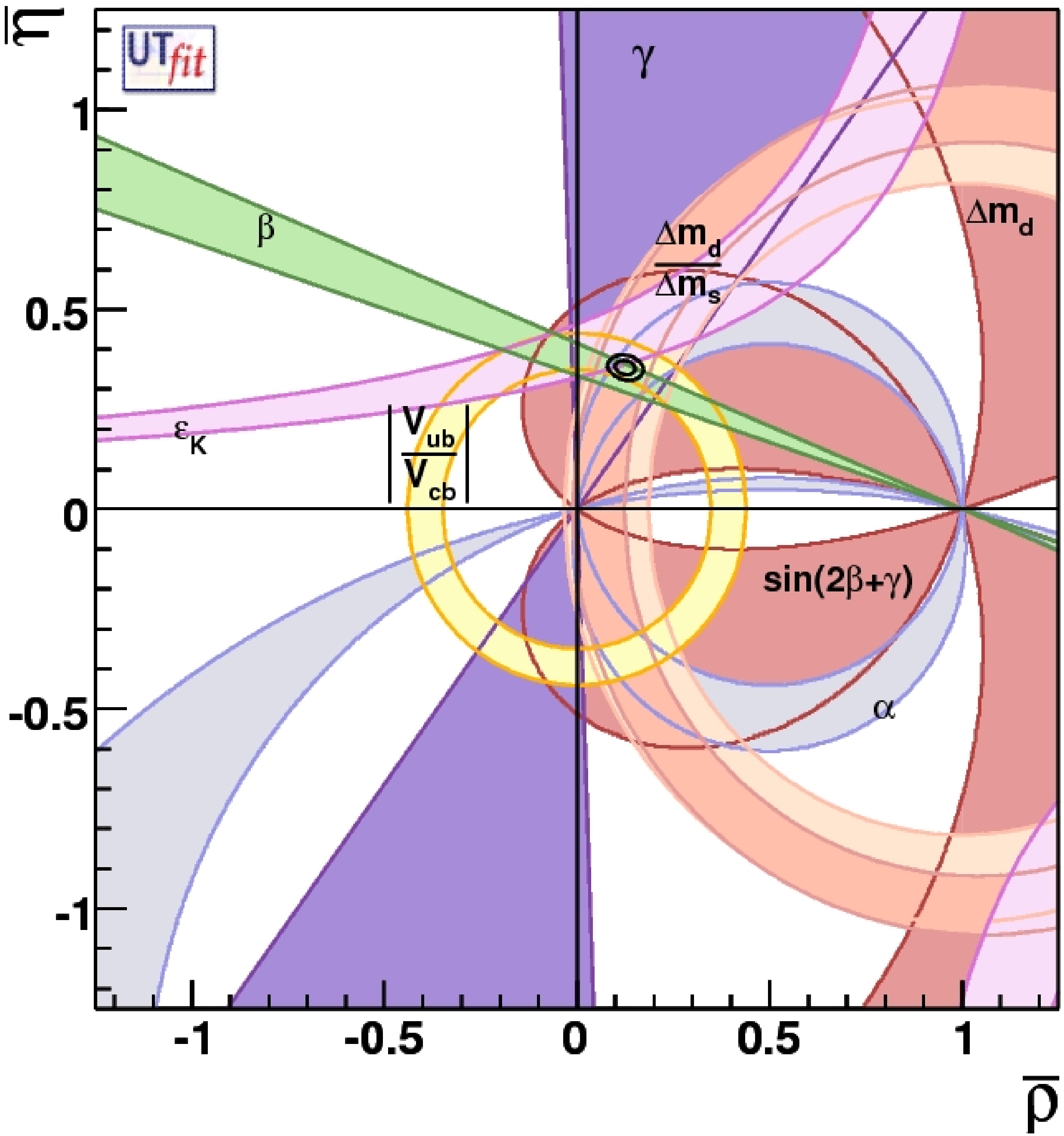
α combined: (91 ± 6)° Phys.Rev.D76:014015,2007

γ combined: (74 ± 11)° U (-106 ± 11)°



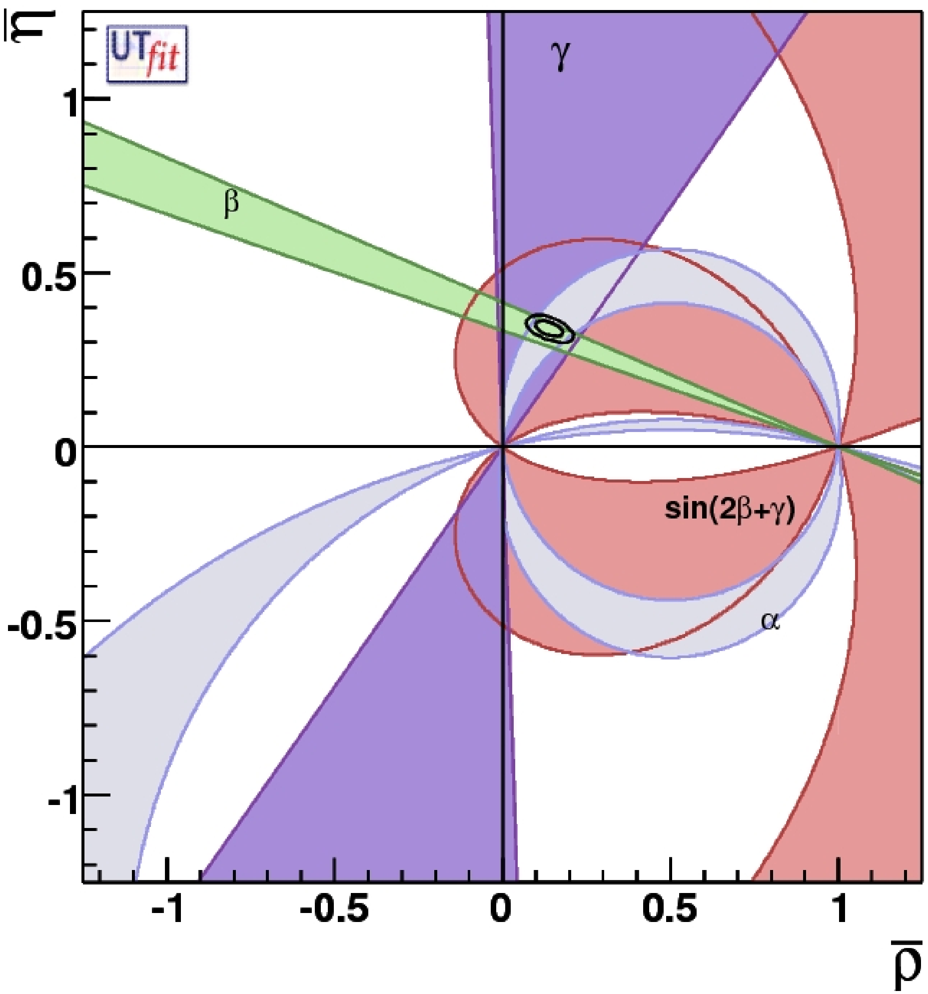
unitarity Triangle analysis in the SM

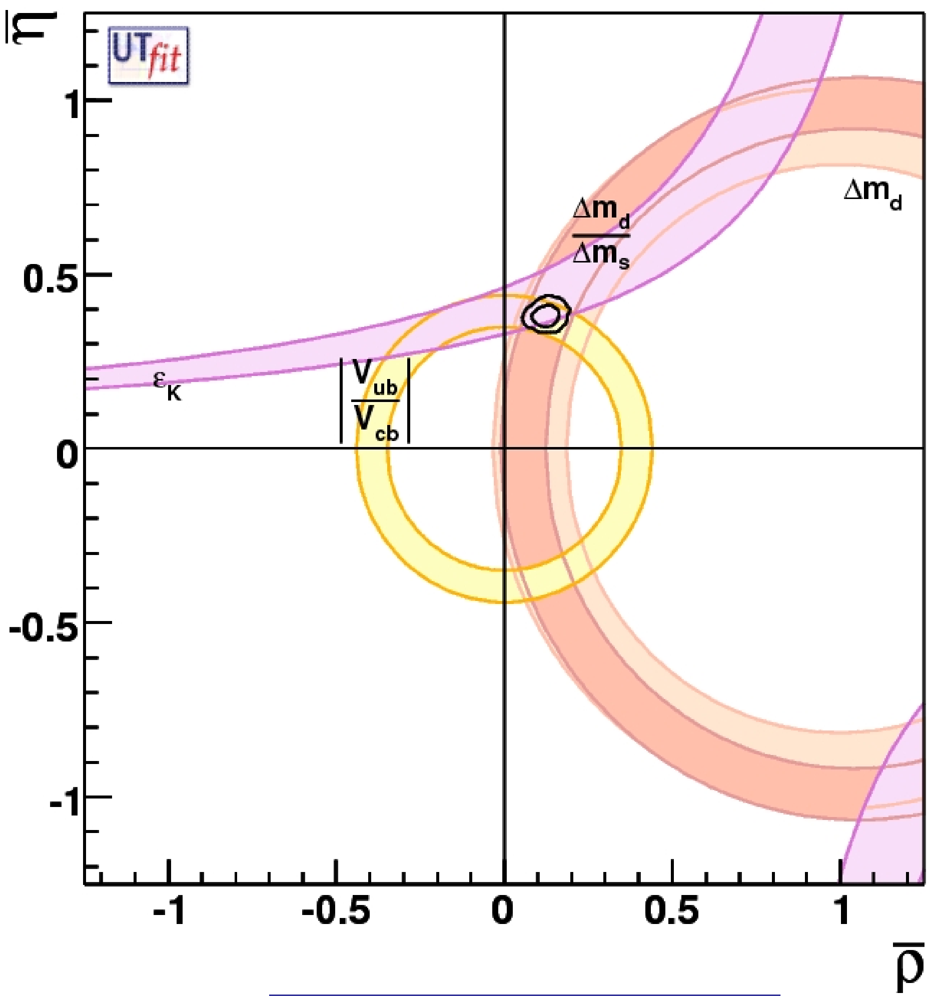
levels @
95% Prob



$\bar{\rho}$ = 0.130 ± 0.020
$\bar{\eta}$ = 0.355 ± 0.013
β = (22 ± 1)°
γ = (70 ± 3)°
α = (87 ± 3)°

angles vs the others





$\bar{\rho} = 0.140 \pm 0.029$
$\bar{\eta} = 0.340 \pm 0.015$

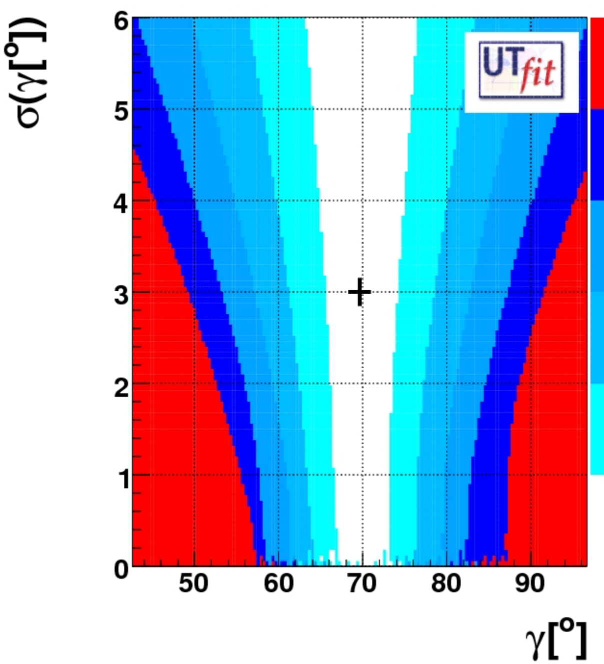
$\bar{\rho} = 0.126 \pm 0.027$
$\bar{\eta} = 0.380 \pm 0.021$

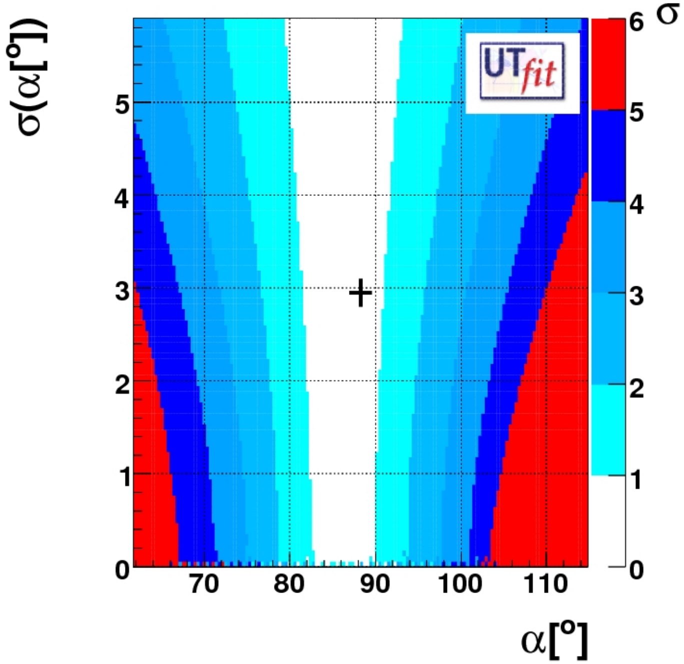
compatibility plots

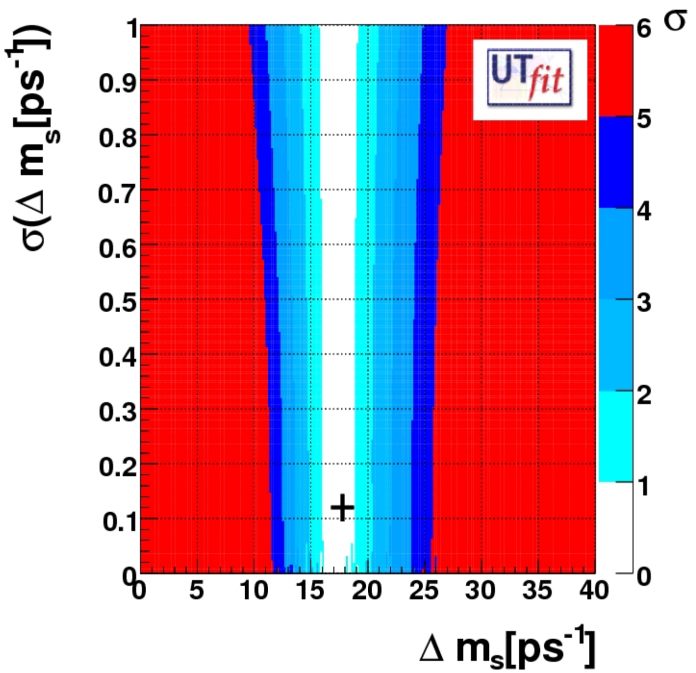
A way to "measure" the agreement of a single measurement with the indirect determination from the fit using all the other inputs: test for the SM description of the flavor physics

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

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







$\gamma_{exp} = (74 \pm 11)°$

$\gamma_{UTfit} = (70 \pm 3)°$

<1σ

$\alpha_{exp} = (91 \pm 6)°$

$\alpha_{UTfit} = (85 \pm 4)°$

<1σ

$\Delta m_{s\,exp} = 17.8 \pm 0.1\ ps^{-1}$

$\Delta m_{s\,UTfit} = 18.2 \pm 1.2\ ps^{-1}$

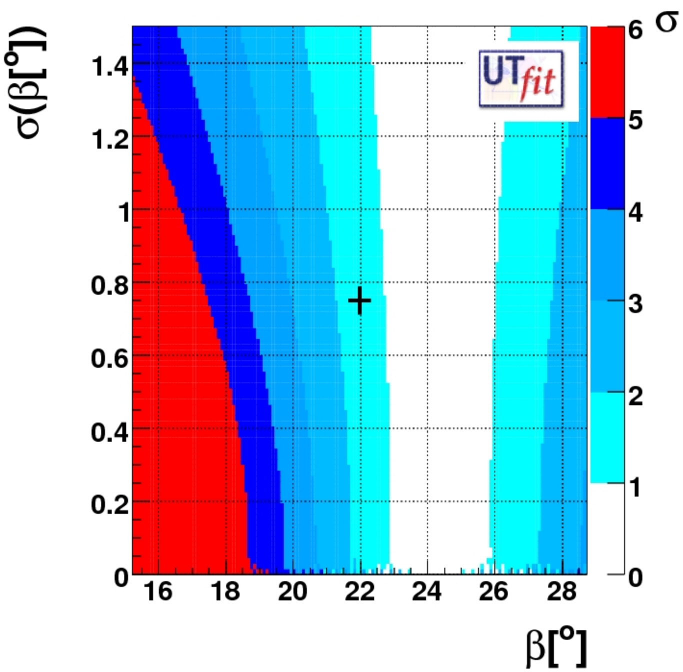
<1σ

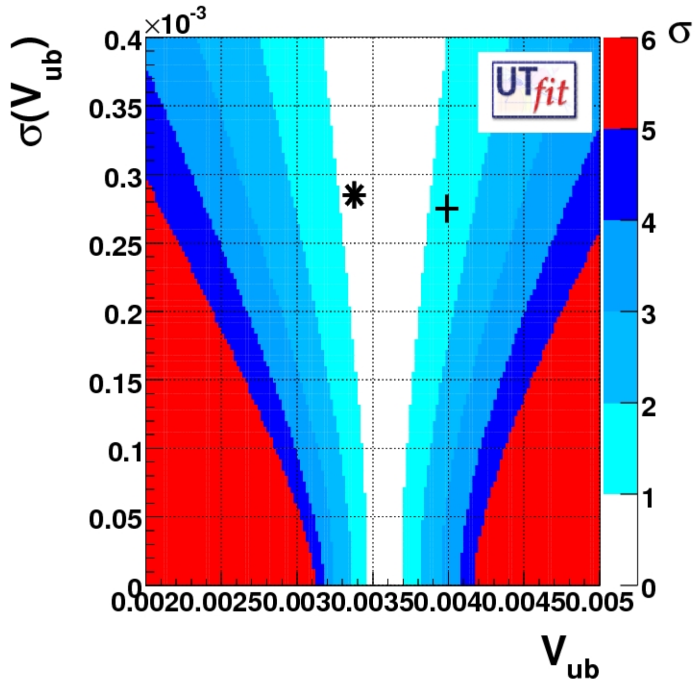
tensions

~2.4σ

$\sin 2\beta_{exp} = 0.655 \pm 0.024$

$\sin 2\beta_{UTfit} = 0.753 \pm 0.034$



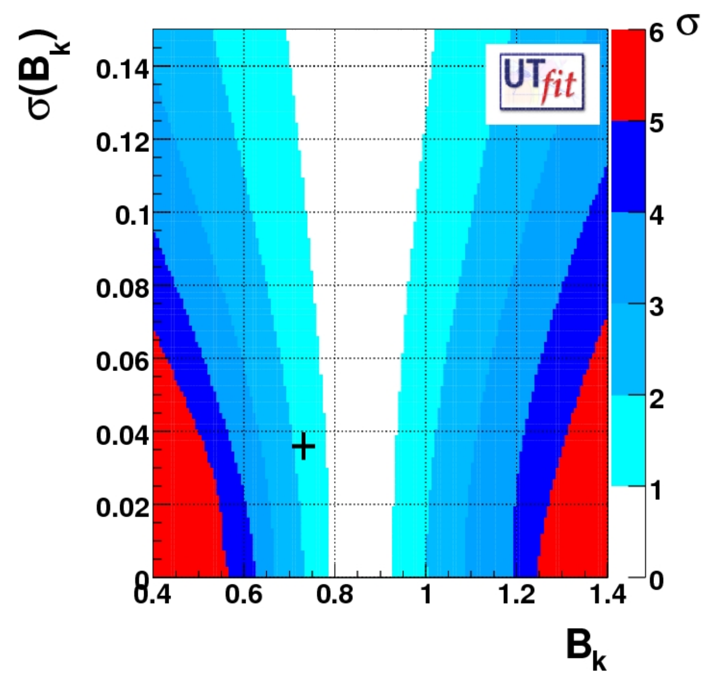


~1.6σ

$B_{K_{exp}} = 0.731 \pm 0.036$

$B_{K_{UTfit}} = 0.855 \pm 0.069$

$\boxed{B_{K_{nolattice}} = 0.869 \pm 0.079}$



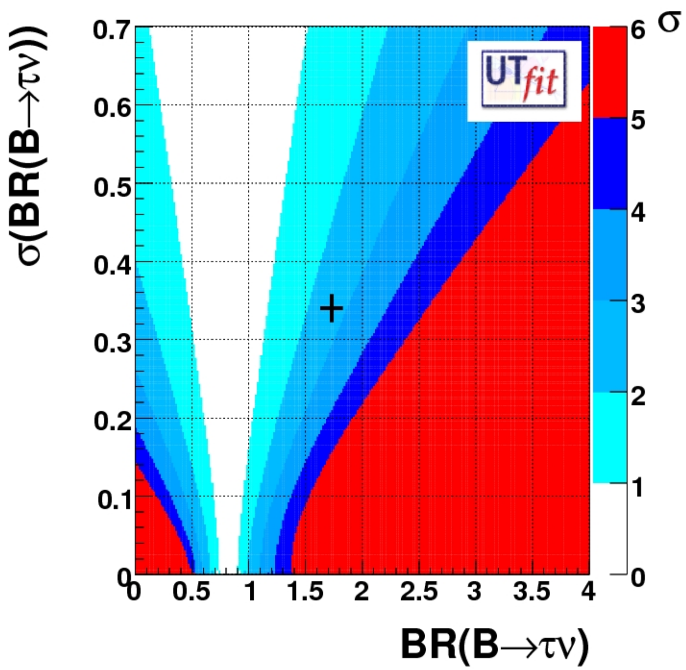
$Vub_{exp} = (37.2 \pm 2.1) \cdot 10^{-4}$

$Vub_{UTfit} = (35.8 \pm 1.1) \cdot 10^{-4}$

<1σ (incl ~1.3σ)

$B \to \tau\nu$

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



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

$B \to \tau\nu$

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 $\tan\beta/m_{H+}$

Two regions selected:

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

incompatible with semileptonic decays
$BR(B\to D\tau\nu)/BR(B\to D\ell\nu)$ = (49±10)%

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

B→τν

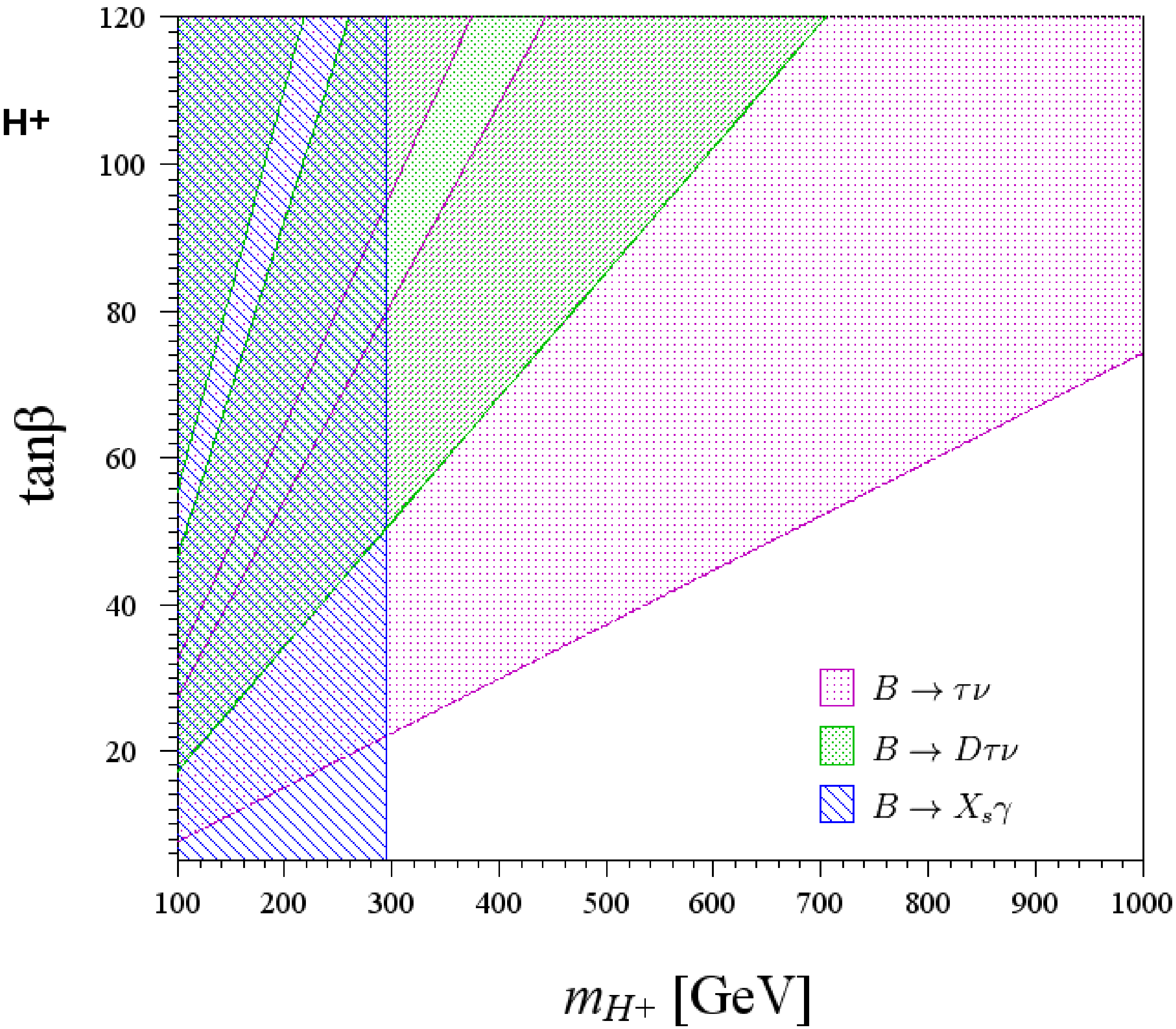
M. Bona *et al*. (UTfit)
Phys.Lett.B 687, 61 (2010)

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$_{H+}$**

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



UTfit beyond the MFV:

1. 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 $\Delta F=2$ transitions

2. perform a $\Delta F=2$ EFT analysis to put bounds on the NP scale
   - consider different choices of the FV and CPV couplings

generic NP parameterization:

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

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

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

Observables:

$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM} \qquad \varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

$$A_{CP}^{B_d \to J/\psi K_s} = \sin 2(\beta + \phi_{B_d}) \qquad A_{CP}^{B_s \to J/\psi \phi} \sim \sin 2(-\beta_s + \phi_{B_s})$$

$$A_{SL}^q = \mathrm{Im}\left(\Gamma_{12}^q / A_q\right) \qquad \Delta\Gamma^q / \Delta m_q = \mathrm{Re}\left(\Gamma_{12}^q / A_q\right)$$

B_s sector:

We now use the combined TeVatron likelihood including frequentistic analysis of systematic errors (~20 parameters varied at ±5σ). No new CDF result.

New D0 result on dimuon charged asymmetry.

For the B_s analysis, we use an improved theoretical prediction for $\Delta\Gamma$:

$$\Delta\Gamma_s / \Gamma_s = 0.14 \pm 0.02$$

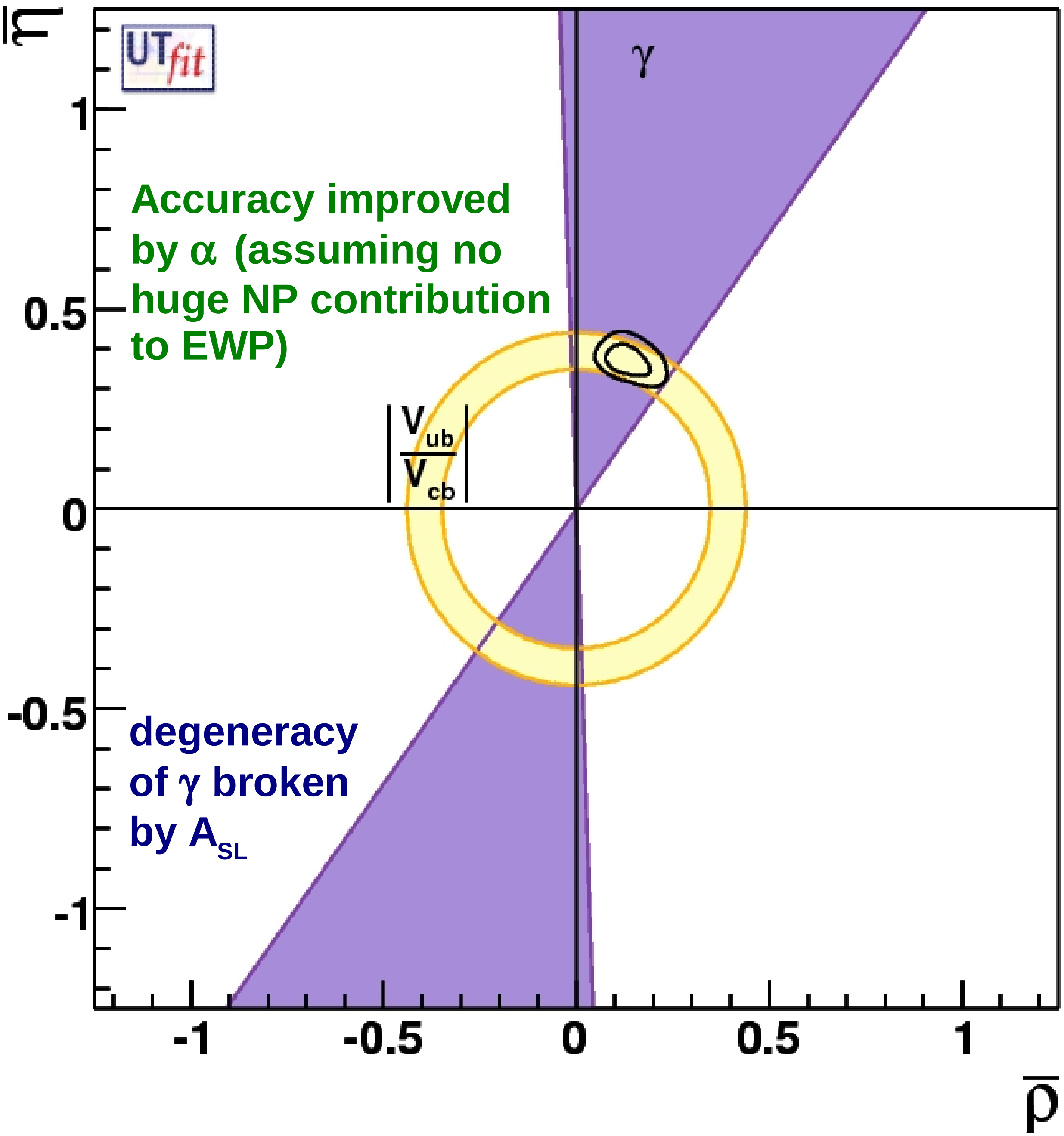
and allow for NP penguin effects in Γ_{12}

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

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

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

NP analysis results



$\bar{\rho} = 0.130 \pm 0.038$
$\bar{\eta} = 0.370 \pm 0.026$

SM is

$\bar{\rho} = 0.130 \pm 0.020$
$\bar{\eta} = 0.355 \pm 0.013$

NP parameter results

[95%] Prob

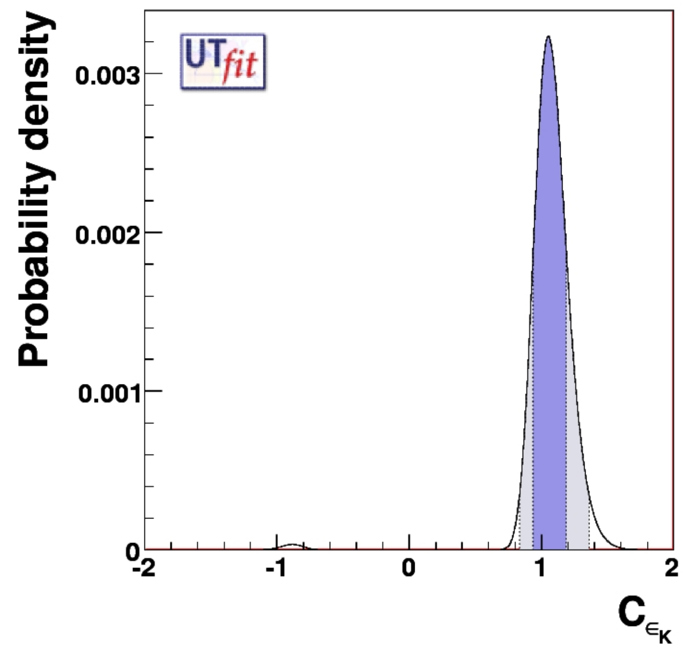
$C_{\varepsilon_K} = 1.06 \pm 0.13$ [0.83,1.36]

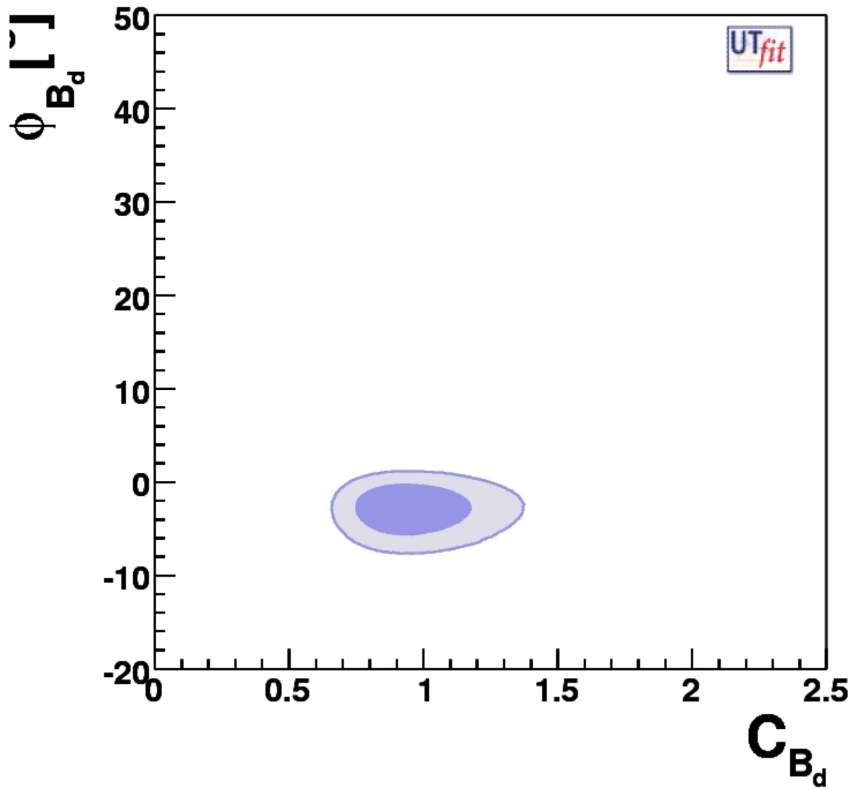
$C_{B_d} = 0.95 \pm 0.14$ [0.70,1.28]

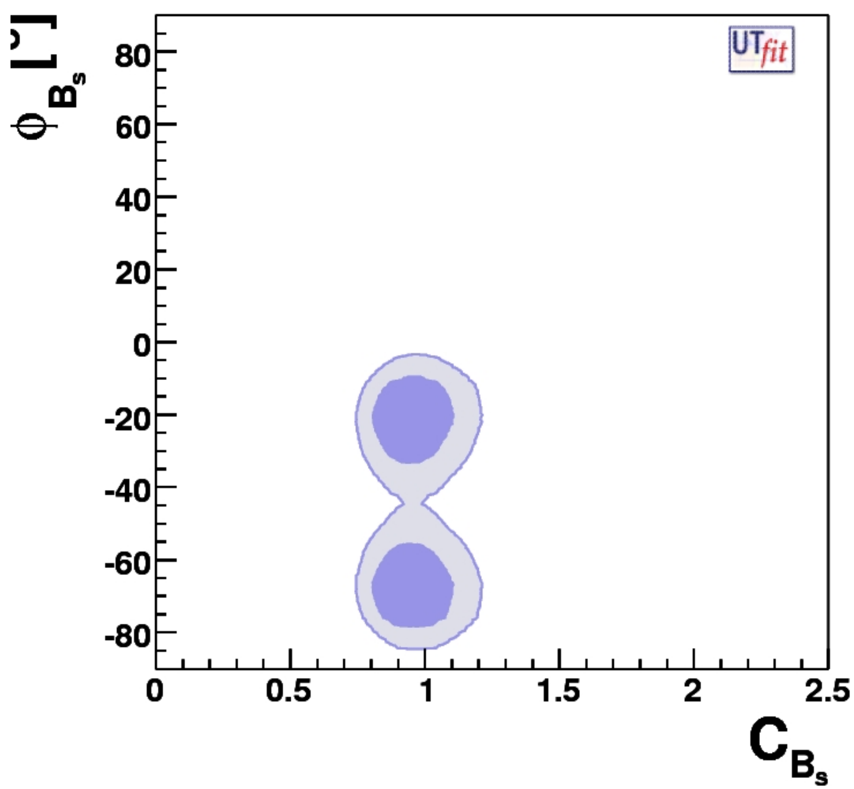
$\phi_{B_d} = (-2.8 \pm 1.7)°$ [-6.7,0.5]°

$C_{B_s} = 0.95 \pm 0.10$ [0.78,1.16]

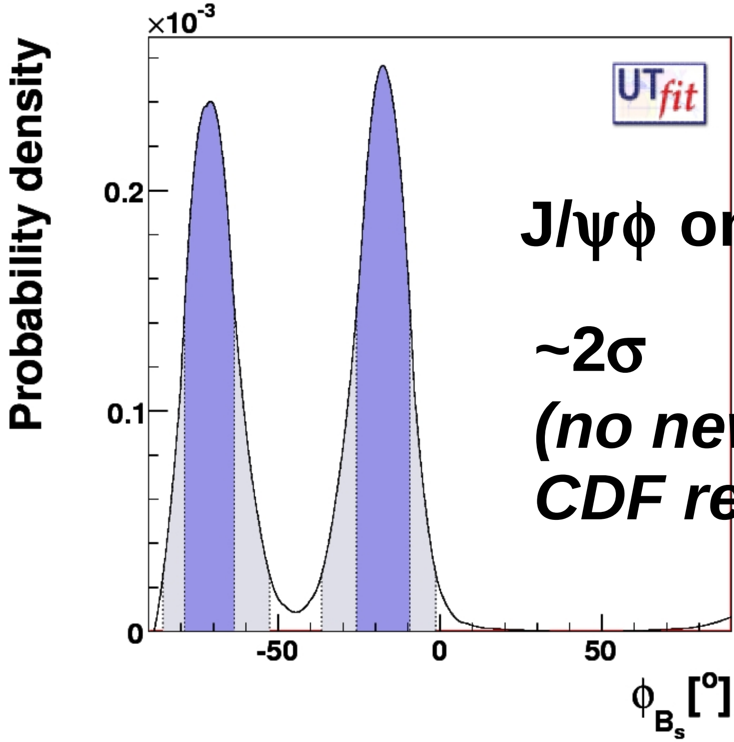
$\phi_{B_s} = (-20 \pm 8)° \cup (-68 \pm 8)°$





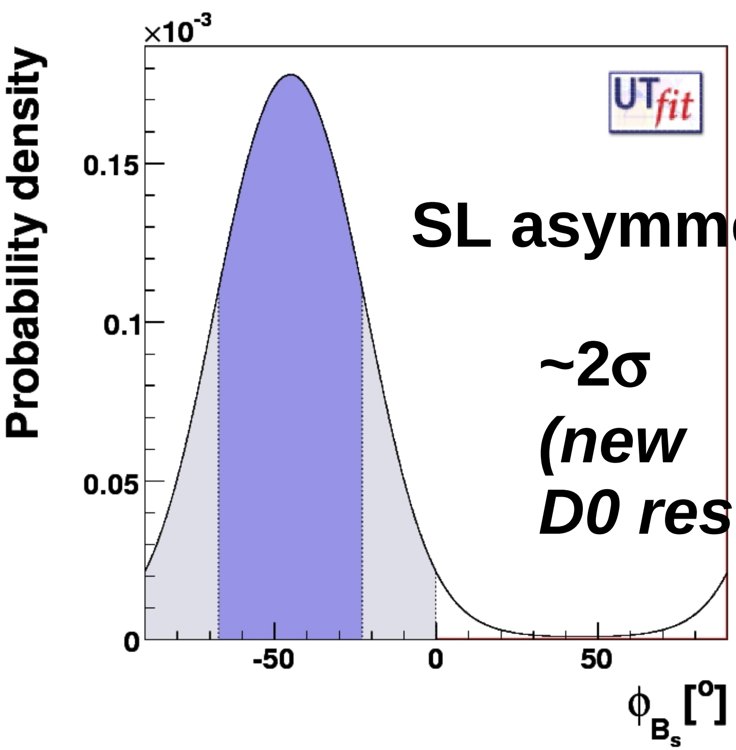


B_s NP phase



J/ψφ only

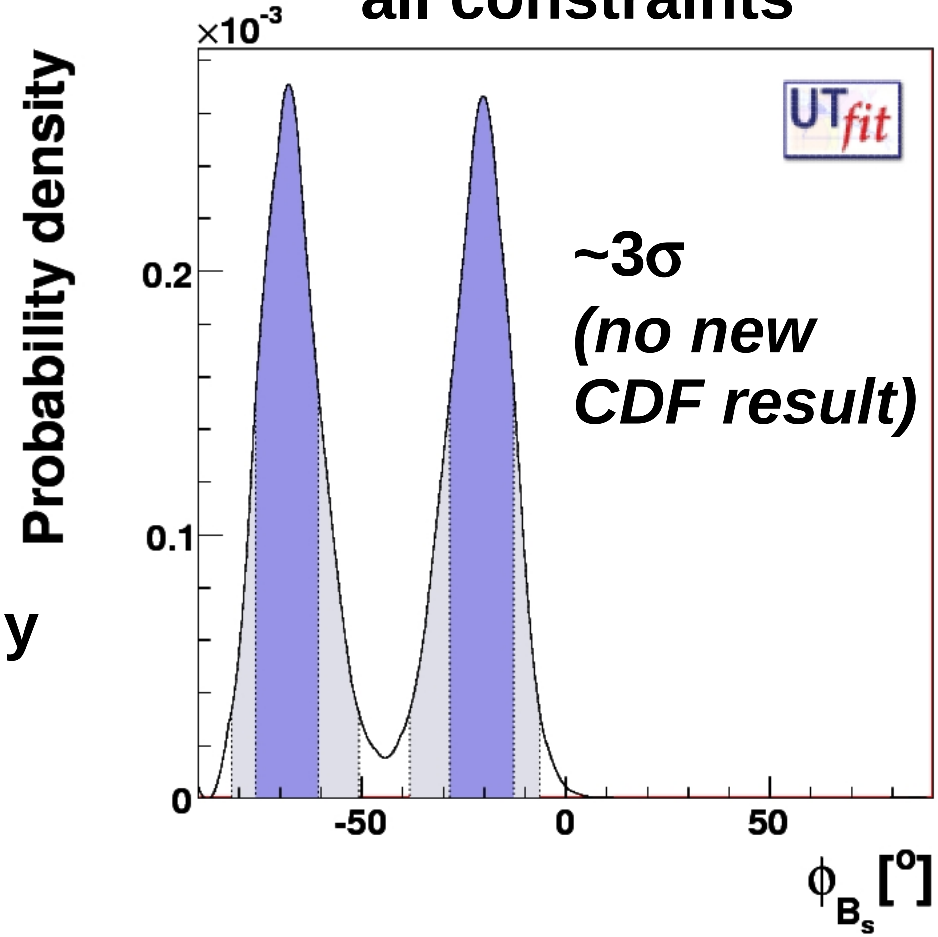
~2σ
(no new CDF result)



SL asymmetries only

~2σ
(new D0 result)

all constraints



~3σ
(no new CDF result)

conclusions

- **SM analysis displays good overall consistency but some tension in sin2β and $B \to \tau\nu$**
- **The two tensions pull $|V_{ub}|$ in opposite directions**
- **Models predicting a suppression of $B \to \tau\nu$ disfavoured by present data: 2HDM & MFV-MSSM @ large tanβ**
- **General UTA provides a precise determination of CKM parameters and NP contributions to $\Delta F=2$ amplitudes**
- ***Effect* in CPV in B_s mixing: it would require new sources of flavour & CPV, natural in many extensions of the SM**

backup

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

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

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

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

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

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

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

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

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

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

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.

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

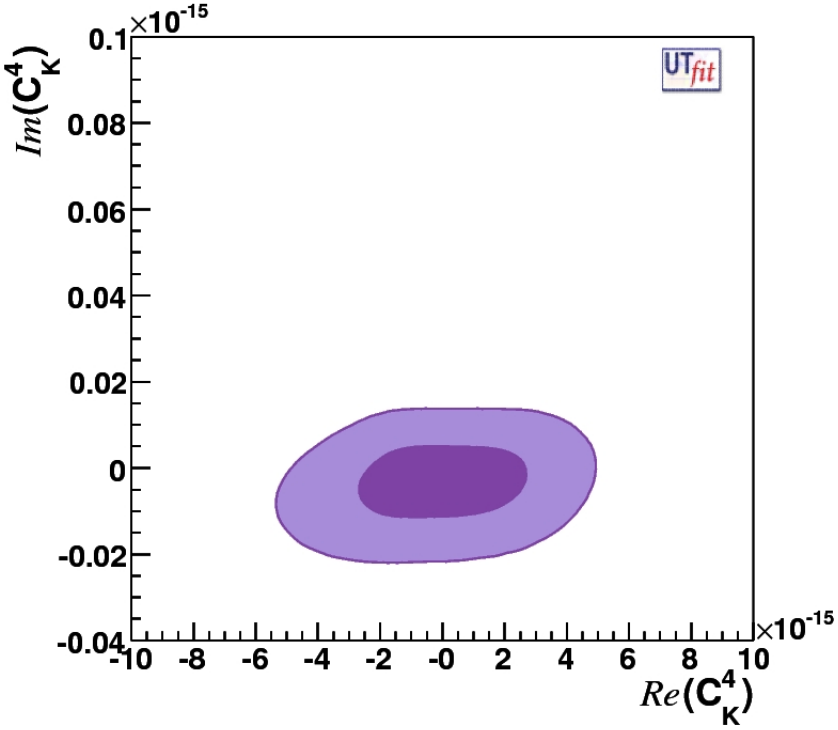
F_{SM} is the combination of CKM factors for the considered process

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

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
$\mathrm{Re}C_K^1$	$[-9.6, 9.6] \cdot 10^{-13}$	$1.0 \cdot 10^3$	0.35
$\mathrm{Re}C_K^2$	$[-1.8, 1.9] \cdot 10^{-14}$	$7.3 \cdot 10^3$	2.0
$\mathrm{Re}C_K^3$	$[-6.0, 5.6] \cdot 10^{-14}$	$4.1 \cdot 10^3$	1.1
$\mathrm{Re}C_K^4$	$[-3.6, 3.6] \cdot 10^{-15}$	$17 \cdot 10^3$	4.0
$\mathrm{Re}C_K^5$	$[-1.0, 1.0] \cdot 10^{-14}$	$10 \cdot 10^3$	2.4
$\mathrm{Im}C_K^1$	$[-4.4, 2.8] \cdot 10^{-15}$	$1.5 \cdot 10^4$	5.6
$\mathrm{Im}C_K^2$	$[-5.1, 9.3] \cdot 10^{-17}$	$10 \cdot 10^4$	28
$\mathrm{Im}C_K^3$	$[-3.1, 1.7] \cdot 10^{-16}$	$5.7 \cdot 10^4$	19
$\mathrm{Im}C_K^4$	$[-1.8, 0.9] \cdot 10^{-17}$	$24 \cdot 10^4$	62
$\mathrm{Im}C_K^5$	$[-5.2, 2.8] \cdot 10^{-17}$	$14 \cdot 10^4$	37

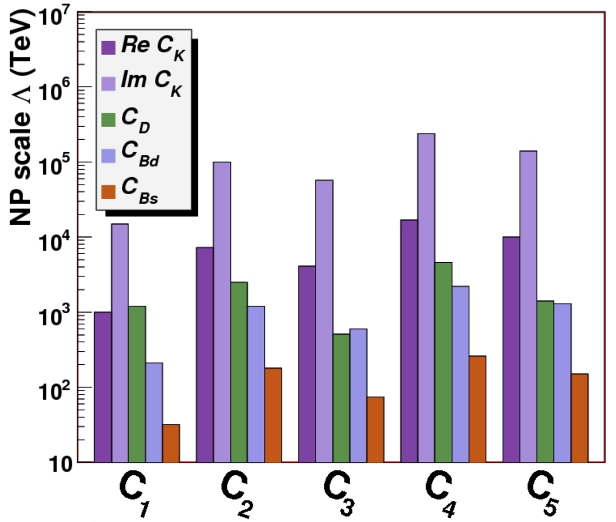


To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by $\alpha_s \sim 0.1$ or by $\alpha_W \sim 0.03$.

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