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

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www.utfit.org

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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, ...)**

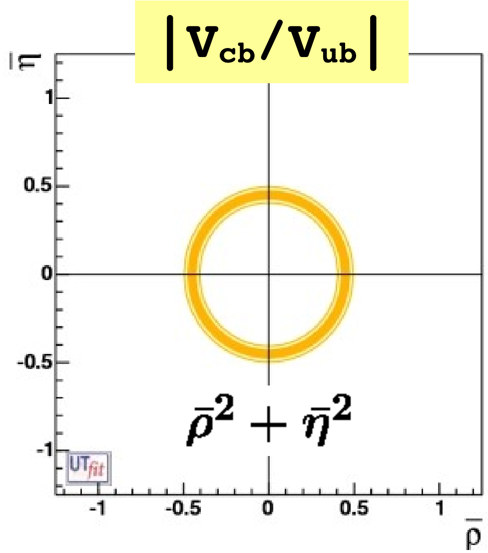
.. and beyond

→ **NP UT analysis:**

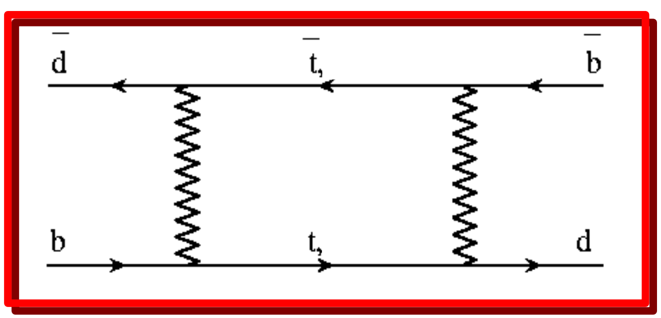
- **model-indipendent analysis**
- **provides limit on the allowed deviations from the SM**
- **NP scale analysis update**

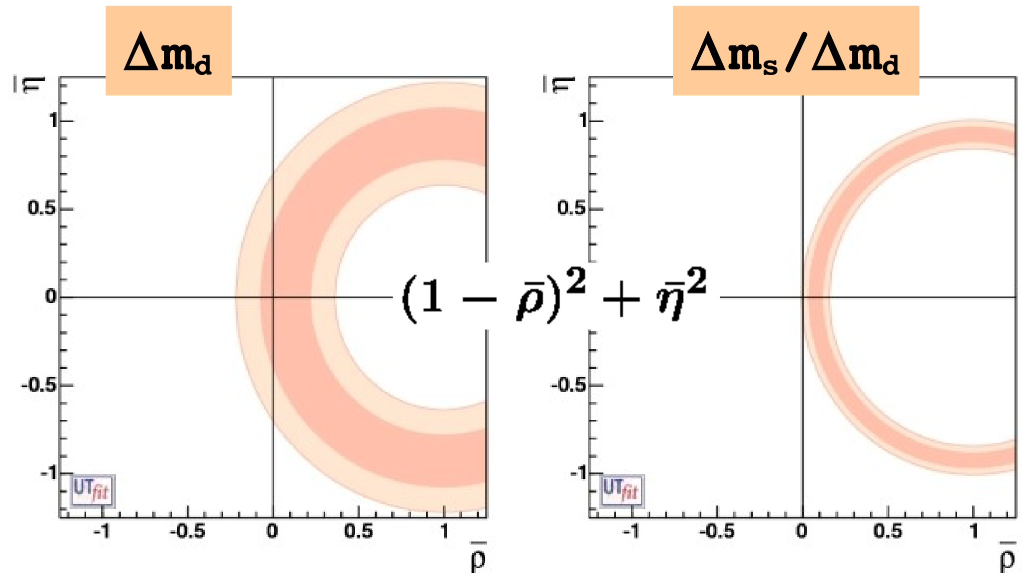
CP-conserving inputs

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



B_d-B_d and B_s-B_s mixing





$\Delta m_d = (0.507 \pm 0.005)\ ps^{-1}$

$\Delta m_s = (17.69 \pm 0.08)\ ps^{-1}$

world average from CDF and LHCb (HFAG)

V_{cb} and V_{ub}

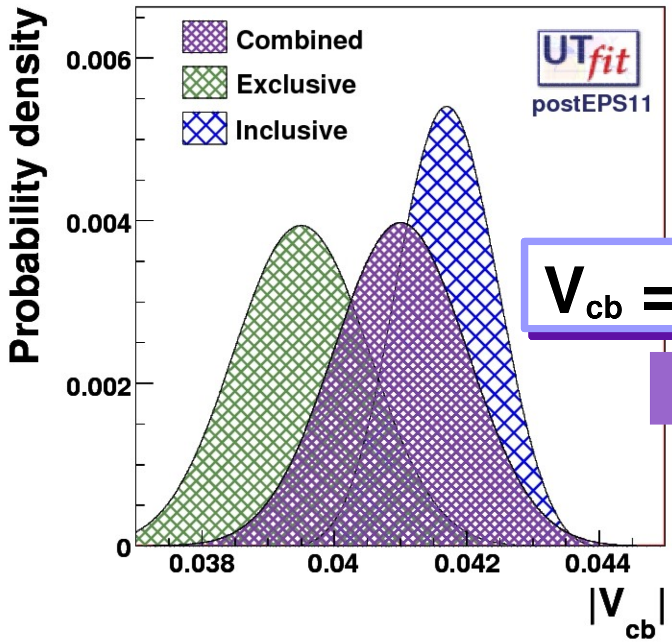
Laiho *et al*

V_{cb} *(excl)* = (39.5 ± 1.0) 10^{-3}

HFAG

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

~2.6σ discrepancy



UTfit input value: average à la PDG

V_{cb} = (41.0 ± 1.0) 10^{-3}

uncertainty ~ 2.4%

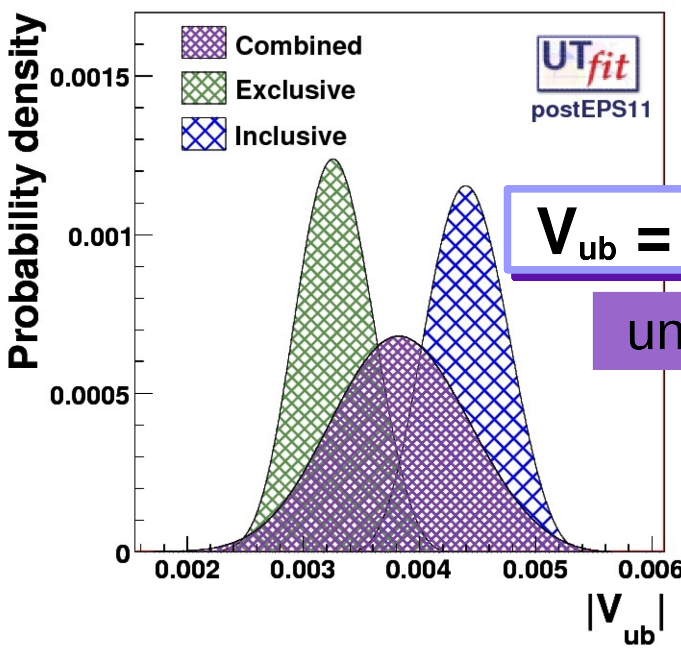
Laiho *et al*

V_{ub} *(excl)* = (3.28 ± 0.30) 10^{-3}

UTfit from HFAG

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

~1.8σ discrepancy

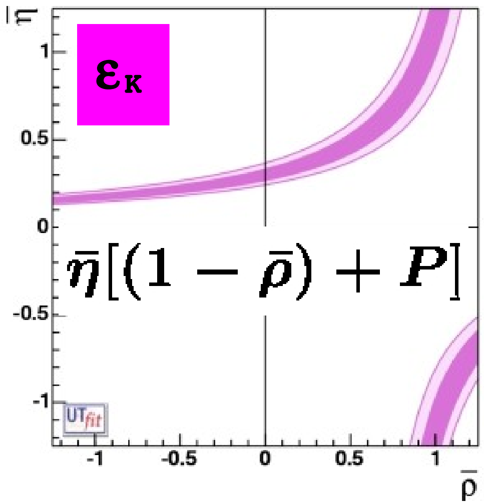


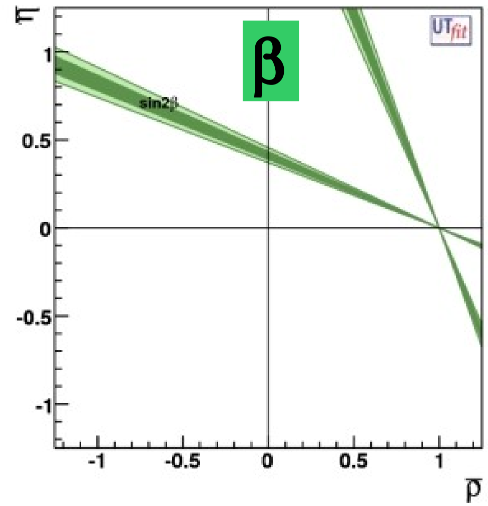
UTfit input value: average à la PDG

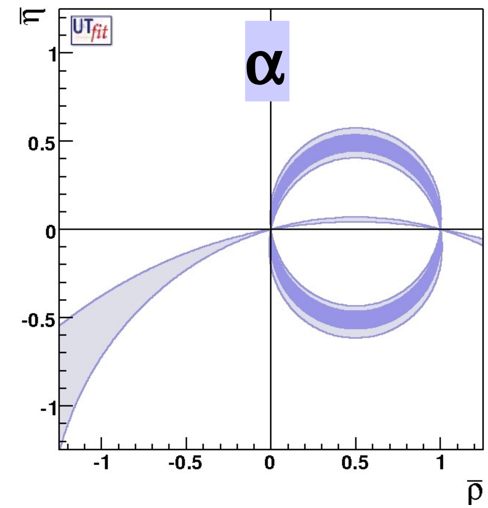
V_{ub} = (3.82 ± 0.56) 10^{-3}

uncertainty ~ 15%

CP-violating inputs







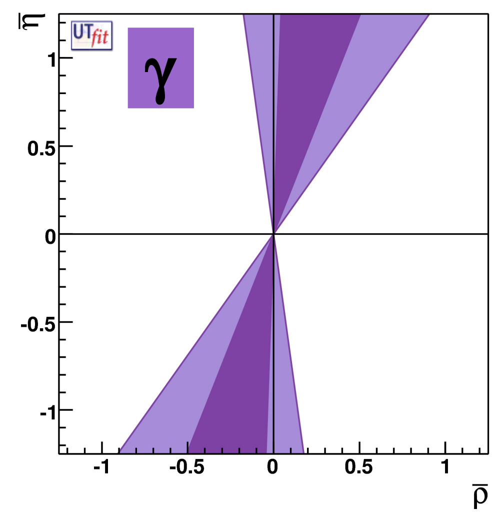
ε_K from K-K mixing

- $B_K = 0.731 \pm 0.036$

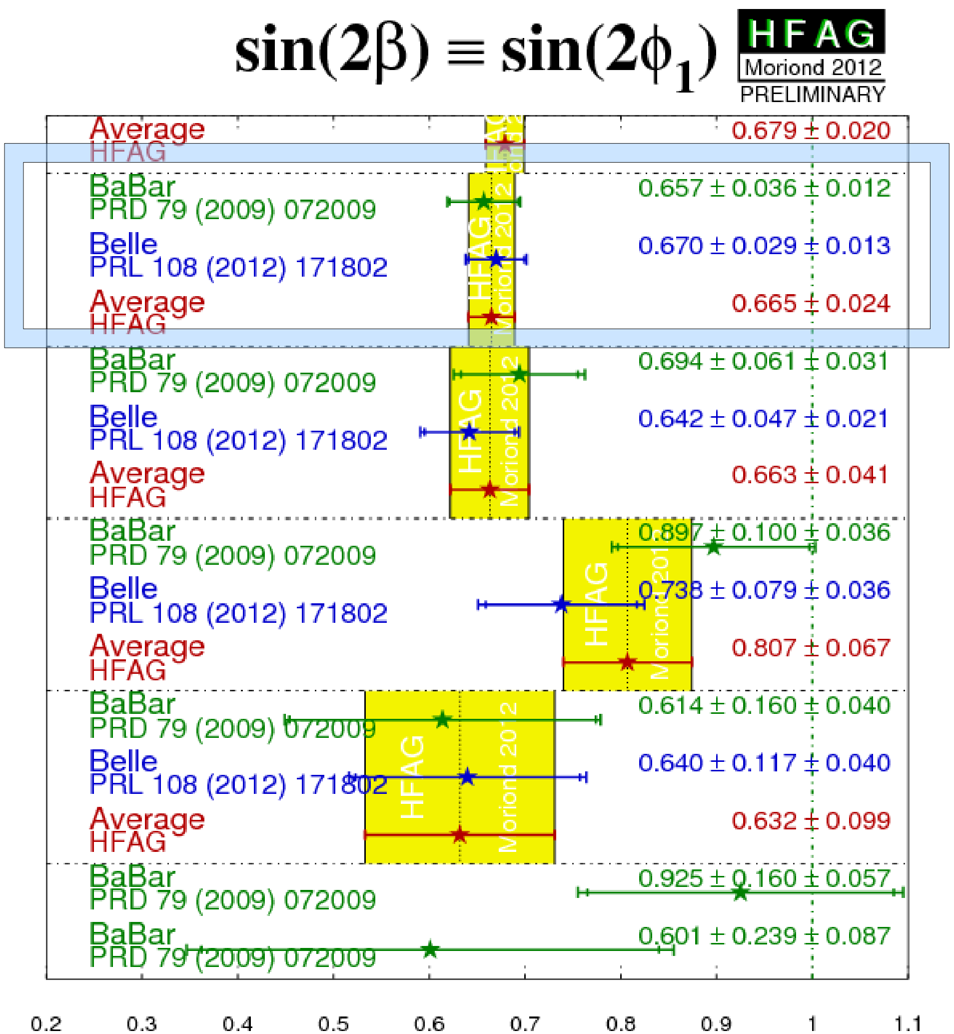
sin2β from $B \rightarrow J/\psi K^0$ + theory

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

γ from $B \rightarrow DK$ decays (tree level)



Latest sin2β results:



BABAR Collaboration
Physical Review D 79:072009, 2009

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

sin2β = 0.666 ± 0.031 ± 0.013

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

sin2β = 0.663 ± 0.025 ± *0.013*

Belle Collaboration
Moriond EW 2011

UTfit input value

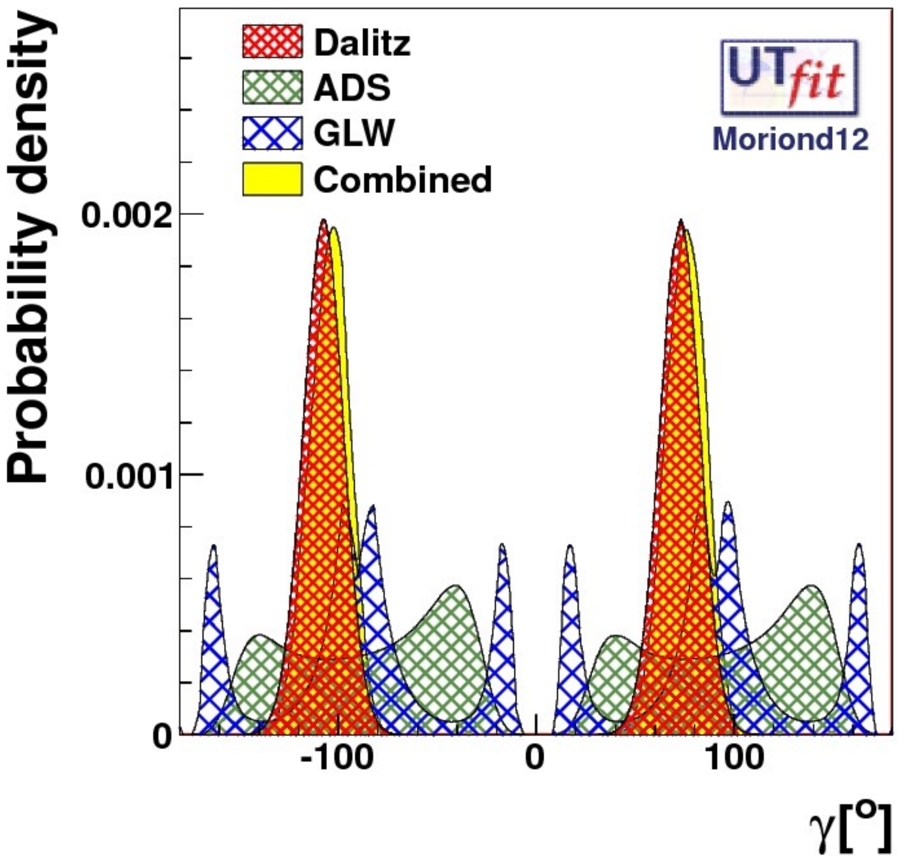
$\sin 2\beta(J/\psi K^0) = 0.665 \pm 0.024$

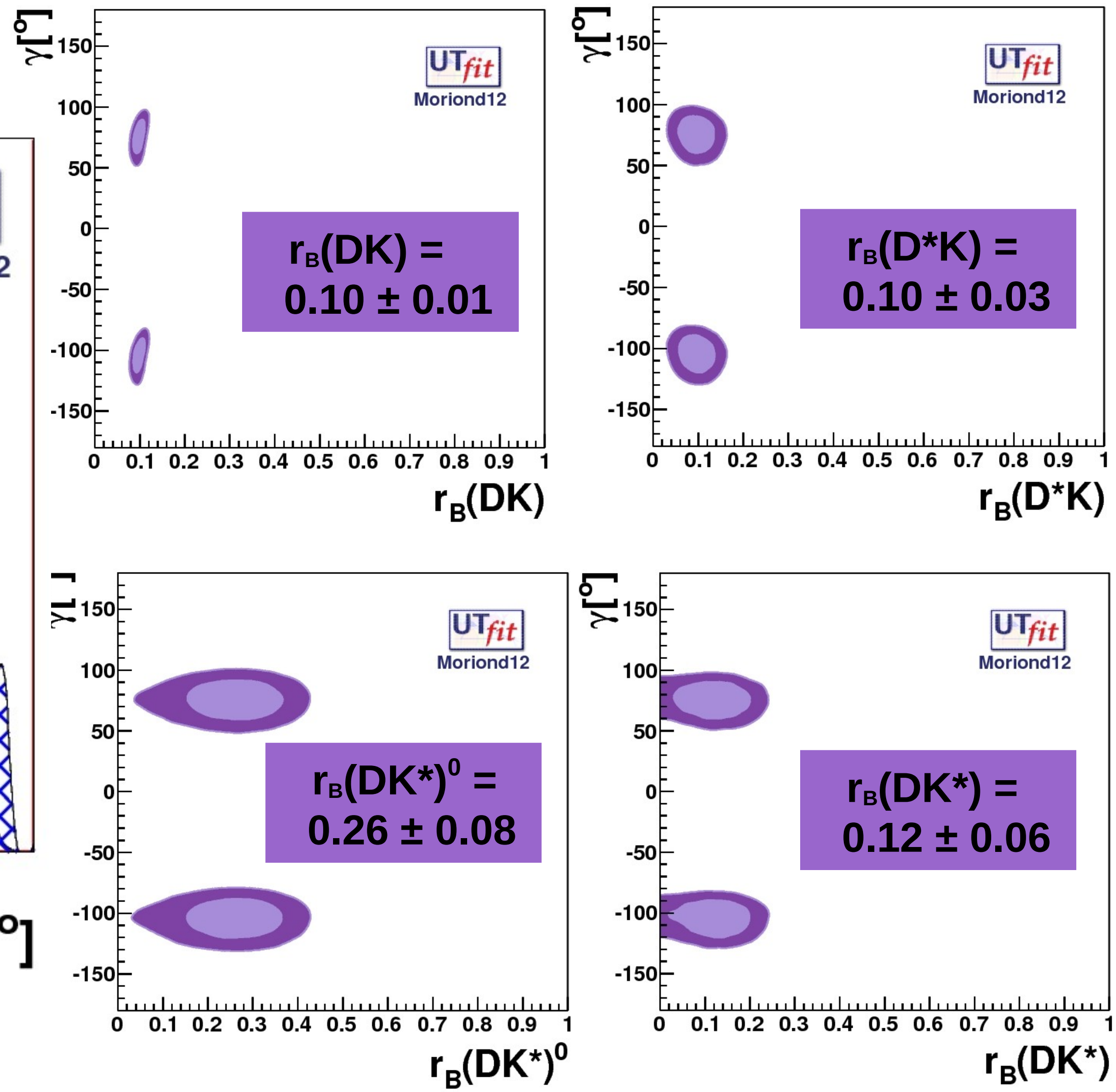
data-driven theoretical uncertainty

$\Delta S = 0.000 \pm 0.012$

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

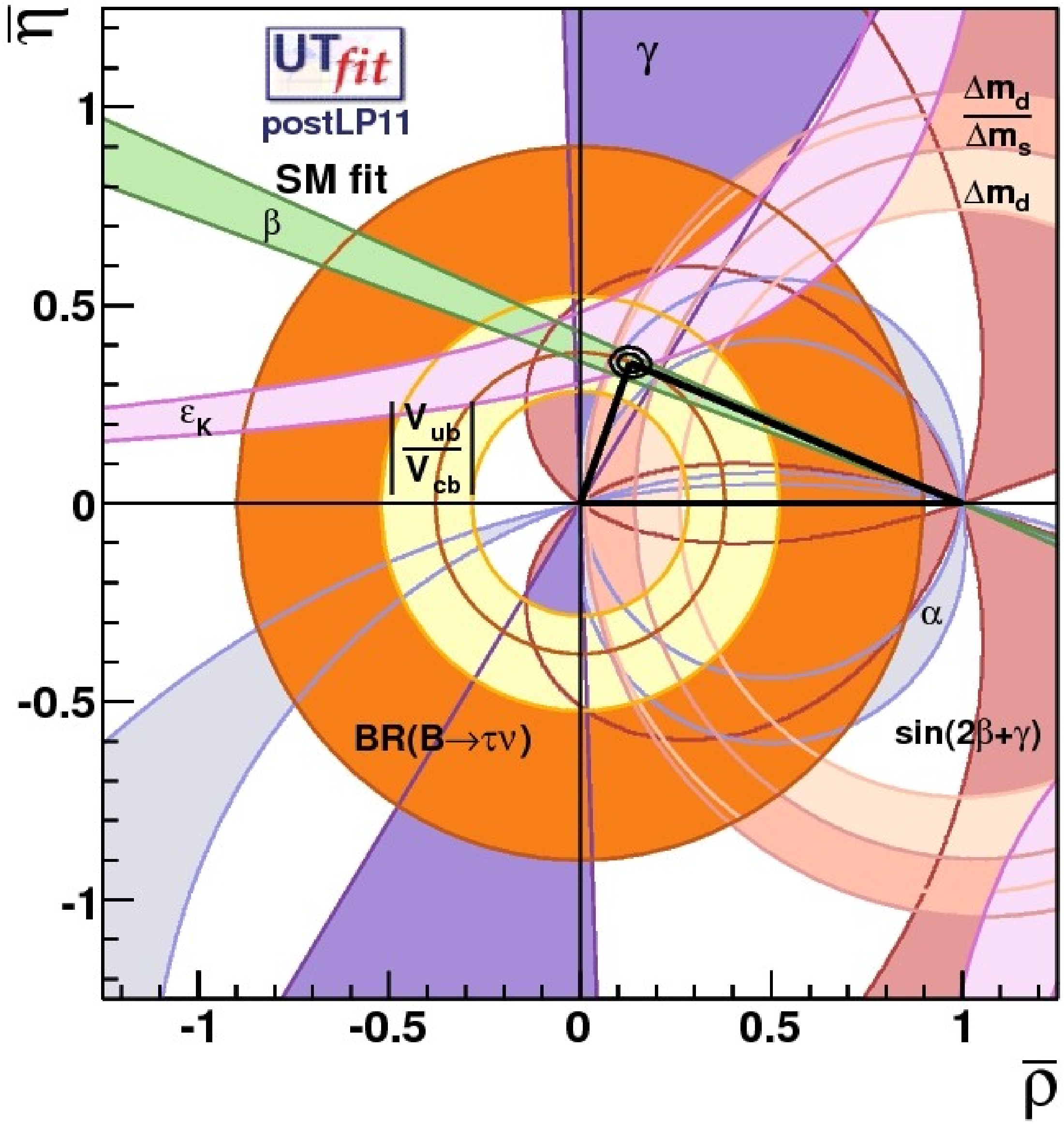
γ and DK trees





$\gamma = (75.5 \pm 10.5)^{o}$

Unitarity Triangle analysis in the SM



levels @
95% Prob

$\bar{\rho}$ **= 0.131 ± 0.022**

$\bar{\eta}$ **= 0.354 ± 0.015**

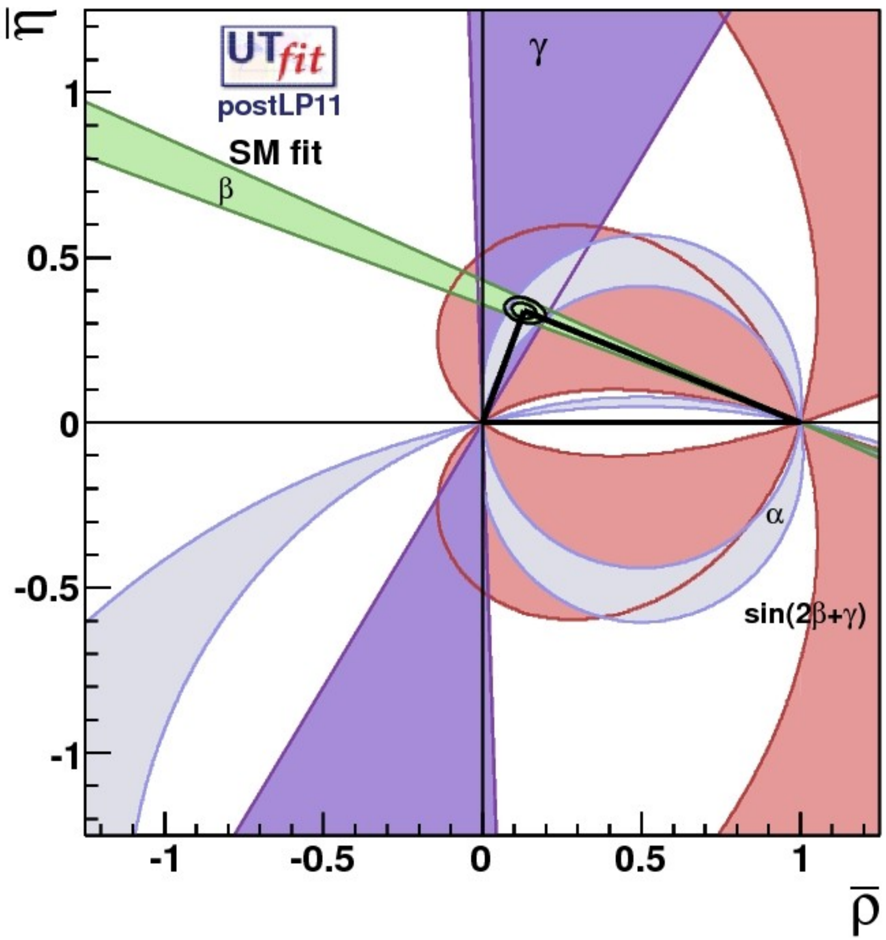
β = (22 ± 1)°

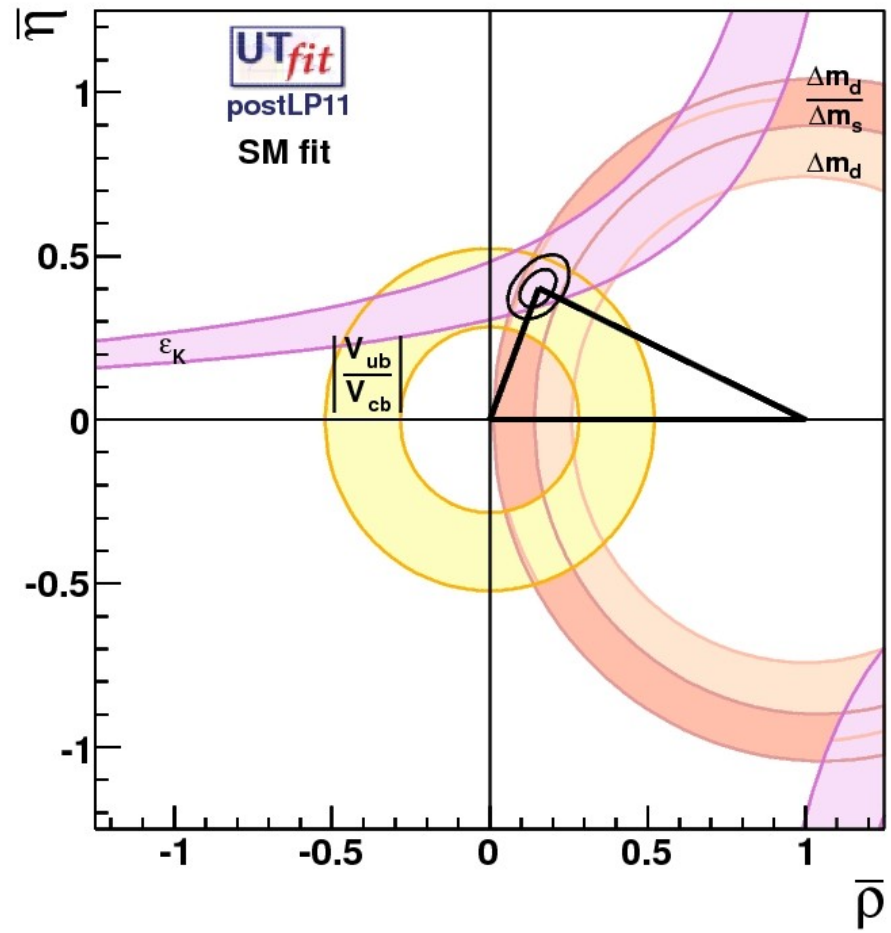
γ = (70 ± 3)°

α = (88 ± 3)°

angles vs the others

levels @
95% Prob





$\bar{\rho} = 0.130 \pm 0.027$
$\bar{\eta} = 0.338 \pm 0.016$

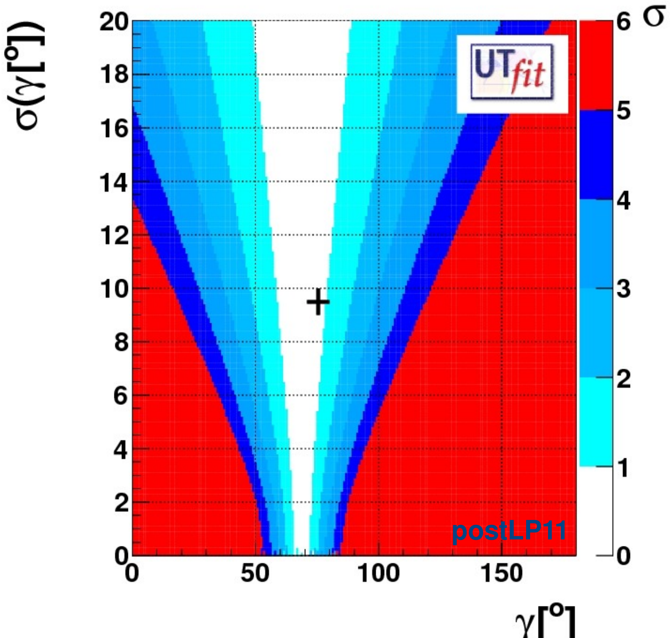
$\bar{\rho} = 0.154 \pm 0.038$
$\bar{\eta} = 0.400 \pm 0.038$

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

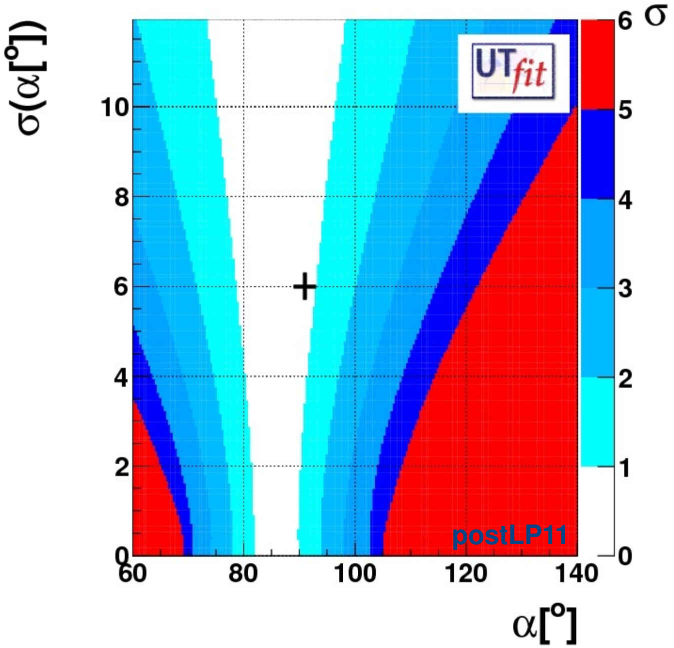
The cross has the coordinates (x,y)=(central value, error) of the direct measurement



$\gamma_{exp} = (75.5 \pm 10.5)^\circ$

$\gamma_{UTfit} = (70 \pm 3)^\circ$

<1σ

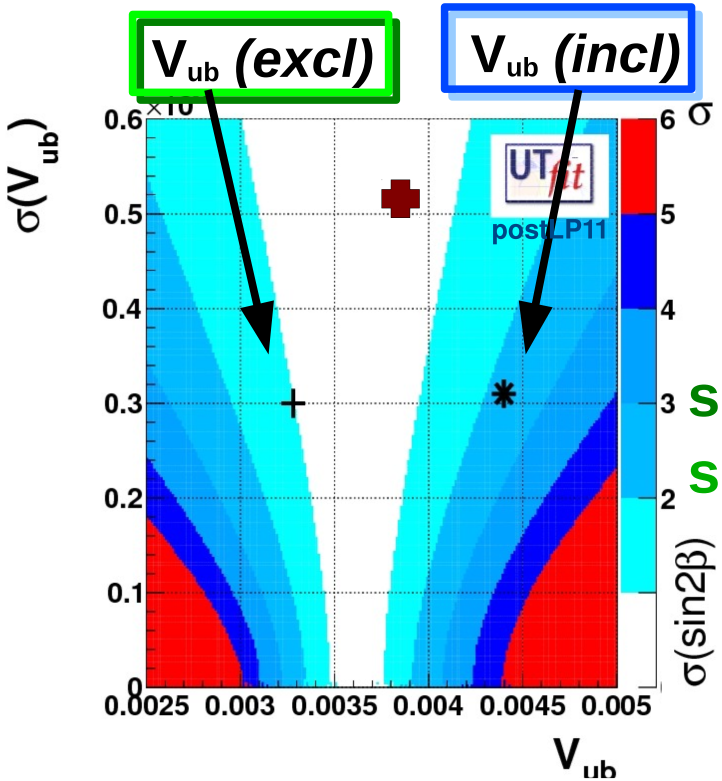


$\alpha_{exp} = (91 \pm 6)^\circ$

$\alpha_{UTfit} = (88 \pm 3)^\circ$

<1σ

tensions



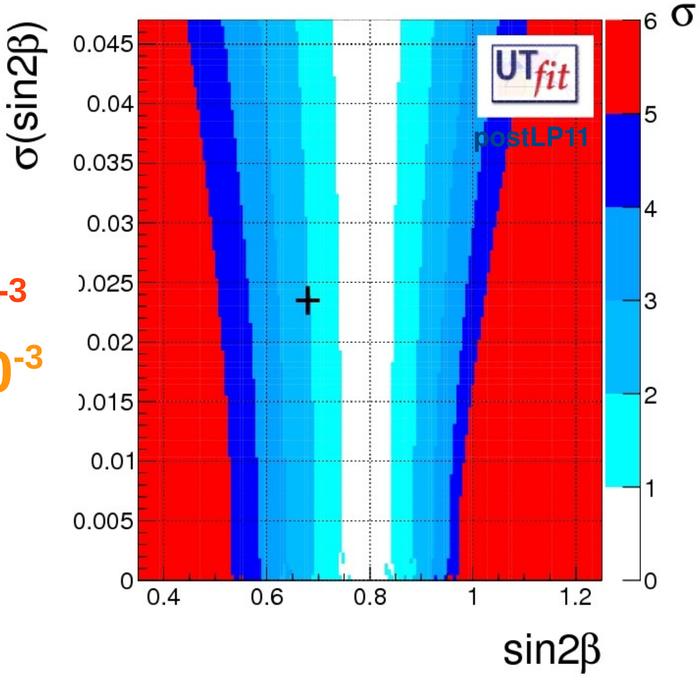
$Vub_{exp} = (3.86 \pm 0.56) \cdot 10^{-3}$

$Vub_{UTfit} = (3.61 \pm 0.14) \cdot 10^{-3}$

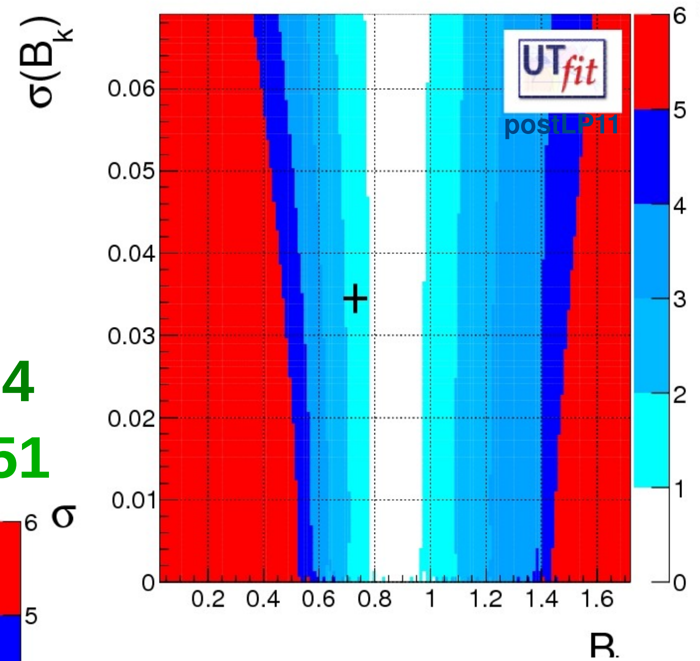
~2.3σ

$\sin 2\beta_{exp} = 0.665 \pm 0.024$

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



~1.5σ

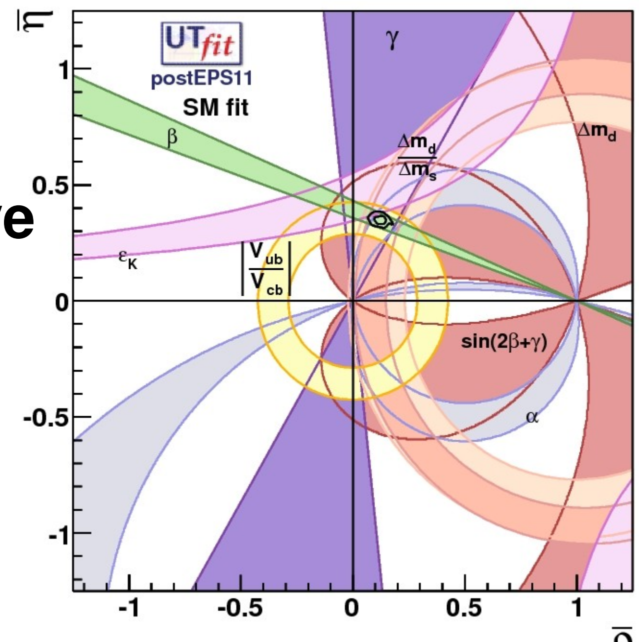


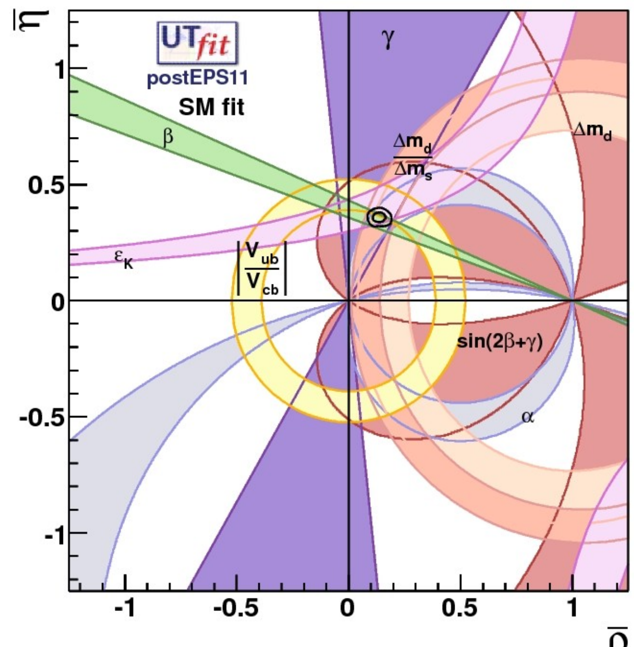
$BK_{exp} = 0.731 \pm 0.036$

$BK_{UTfit} = 0.872 \pm 0.094$

$BK_{nolattice} = 0.85 \pm 0.14$

only exclusive values

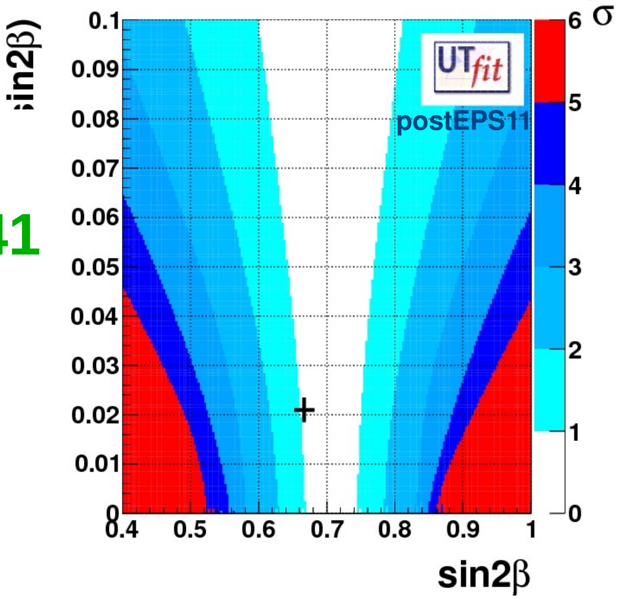


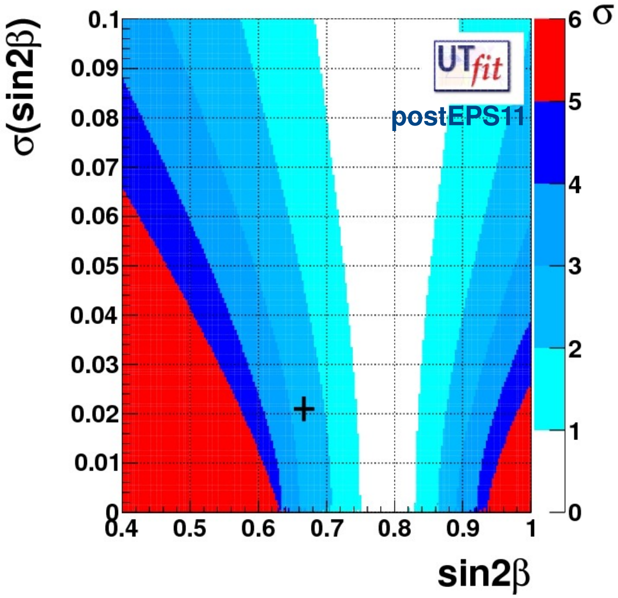


only inclusive values

$\sin 2\beta_{UTfit}$ = 0.706 ± 0.041

~0.8σ





$\sin 2\beta_{UTfit}$ = 0.791 ± 0.041

~2.6σ

$\sin 2\beta_{UTfit}$ = 0.76 ± 0.10 ¬ *no semileptonic*

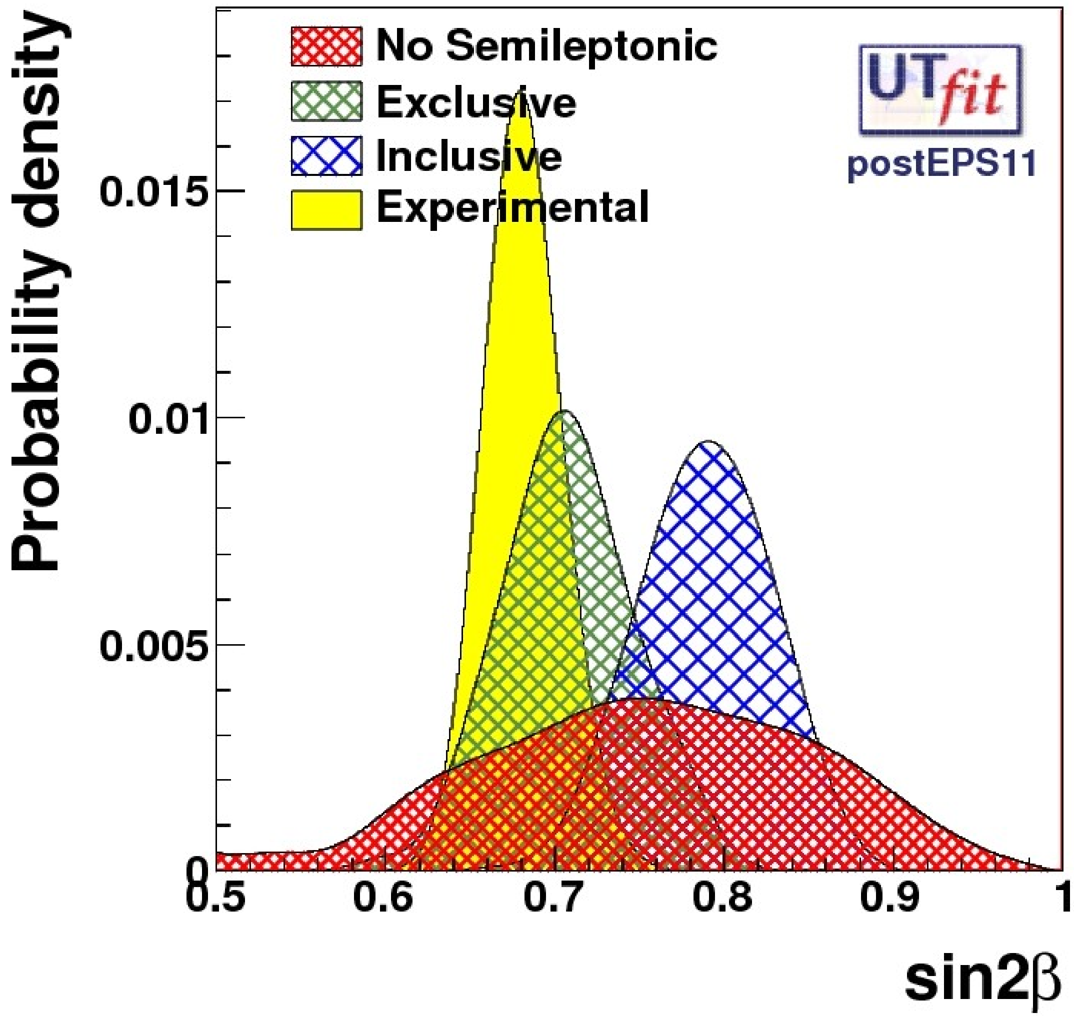
~0.9σ

inclusives vs exclusives

only exclusive values

$\sin 2\beta_{UTfit}$ = 0.706 ± 0.041

~0.8σ



only inclusive values

$\sin 2\beta_{UTfit}$ = 0.791 ± 0.041

~2.6σ

$\sin 2\beta_{UTfit} = 0.76 \pm 0.10$ ¬ *no semileptonic*

~0.9σ

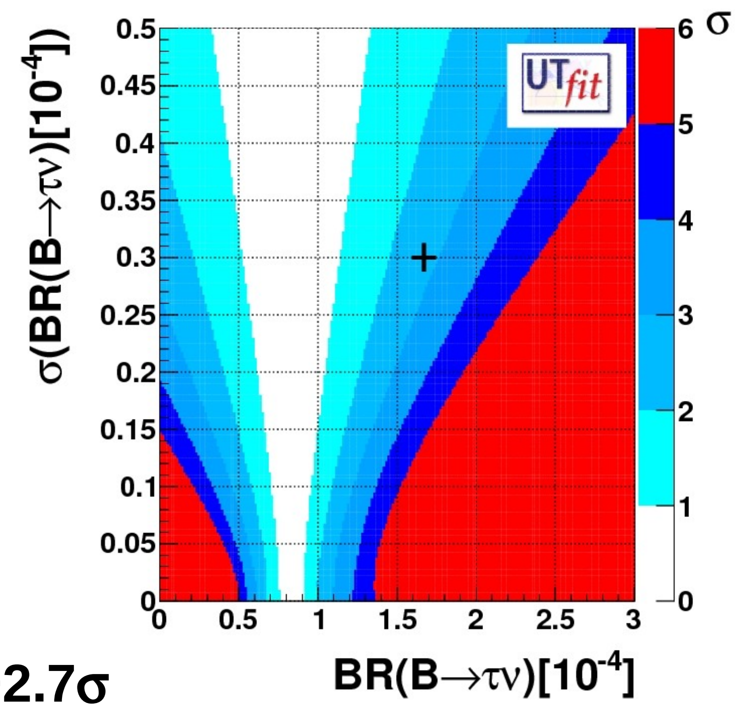
more standard model predictions:

current HFAG world average

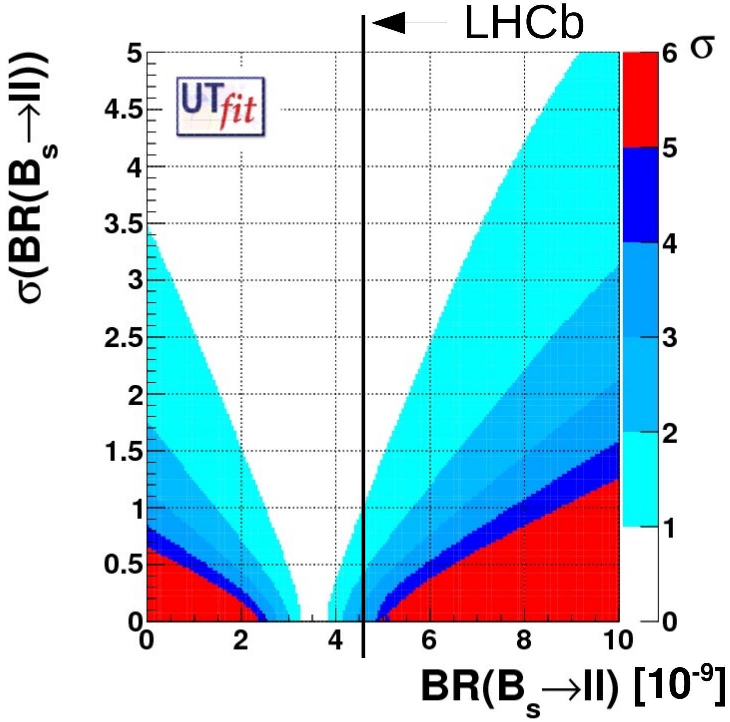
$BR(B \to \tau\nu) = (1.67 \pm 0.30)\ 10^{-4}$

best limit from LHCb

$BR(B_s \to \mu\mu) < 4.5\ 10^{-9}$



~2.7σ



indirect determinations from UT

$BR(B \to \tau\nu) = (0.83 \pm 0.09)\ 10^{-4}$

$BR(B_s \to ll) = (3.54 \pm 0.28)\ 10^{-9}$

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

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

D0
Phys.Rev.D82:012003,2010

$$A^s_{\rm SL} \times 10^2 = -0.17 \pm 0.91$$

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

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

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

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

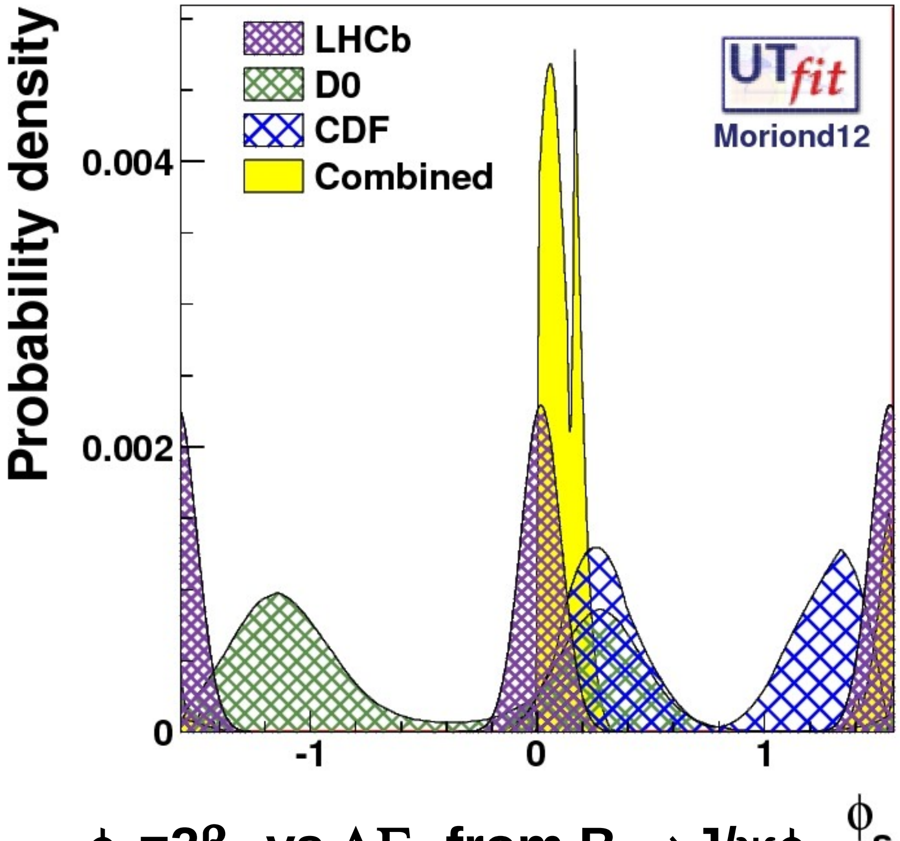
ϕ_s=2β_s vs $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$

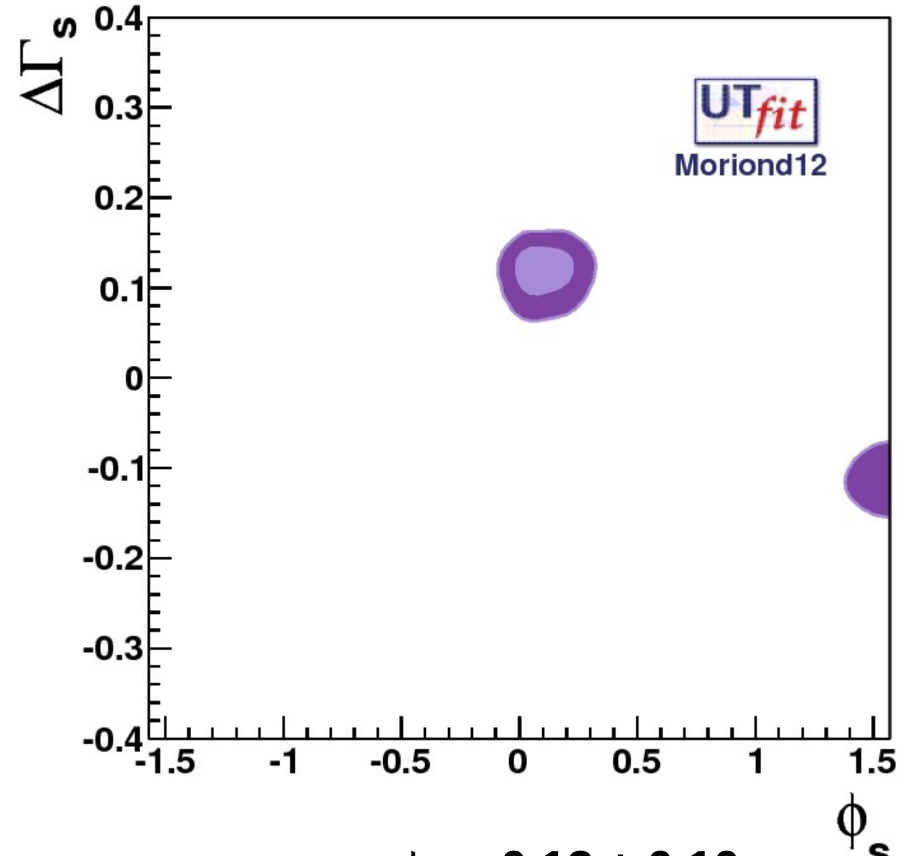
angular analysis as a function of proper time
and b-tagging
additional sensitivity from the $\Delta\Gamma_s$ terms

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

ϕ_s and $\Delta\Gamma_s$:
central values with
gaussian errors from LHCb

new-physics-specific constraints





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

$\phi_s = 0.13 \pm 0.10$

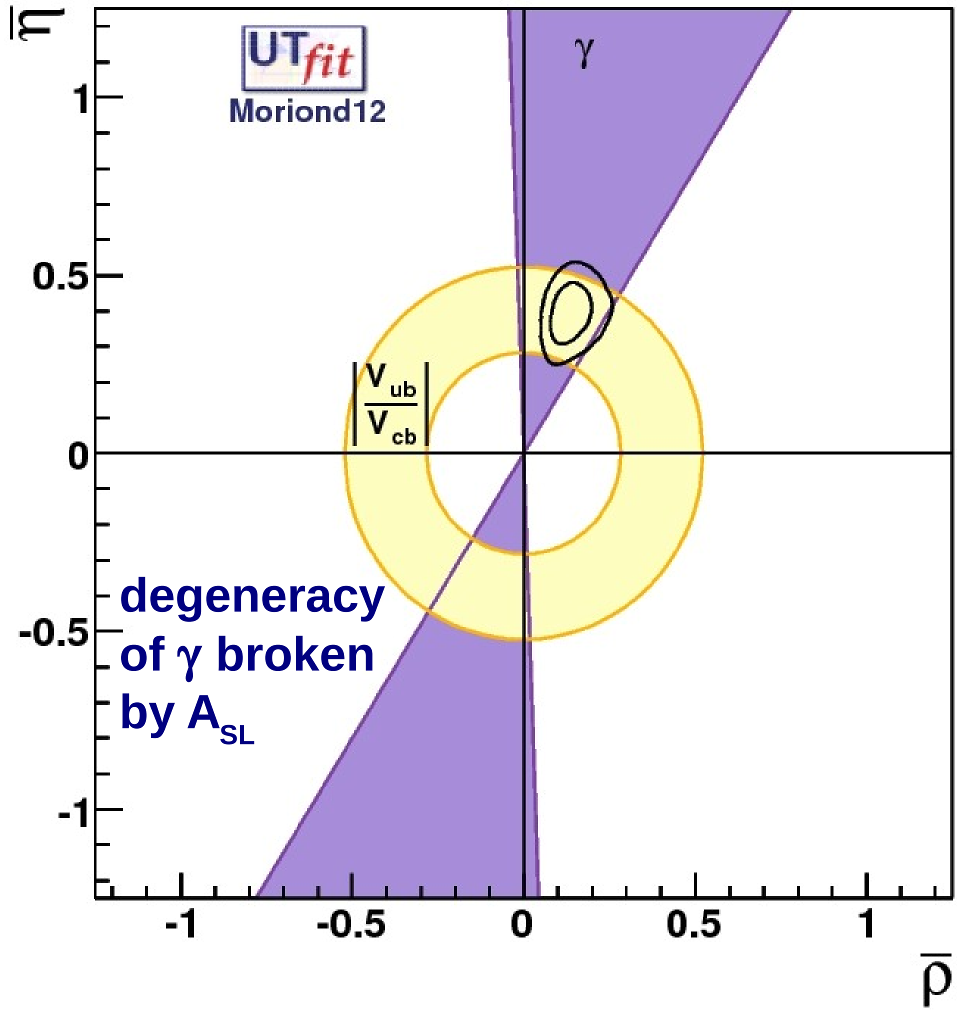
angular analysis as a function of proper time and b-tagging

additional sensitivity from the $\Delta\Gamma_s$ terms

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

ϕ_s and $\Delta\Gamma_s$:
central values with gaussian errors from LHCb

NP analysis results

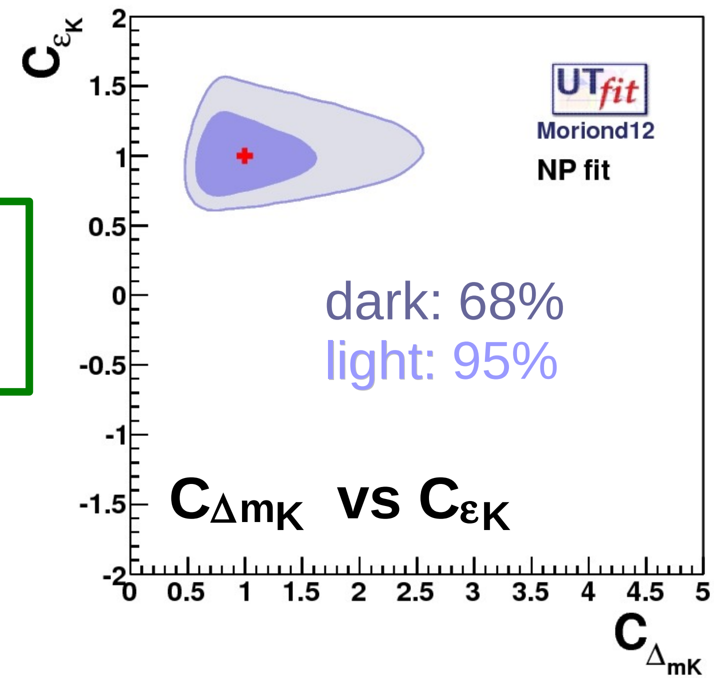


$\bar{\rho} = 0.133 \pm 0.040$
$\bar{\eta} = 0.394 \pm 0.054$

SM is

$\bar{\rho} = 0.131 \pm 0.022$
$\bar{\eta} = 0.354 \pm 0.015$

NP parameter results



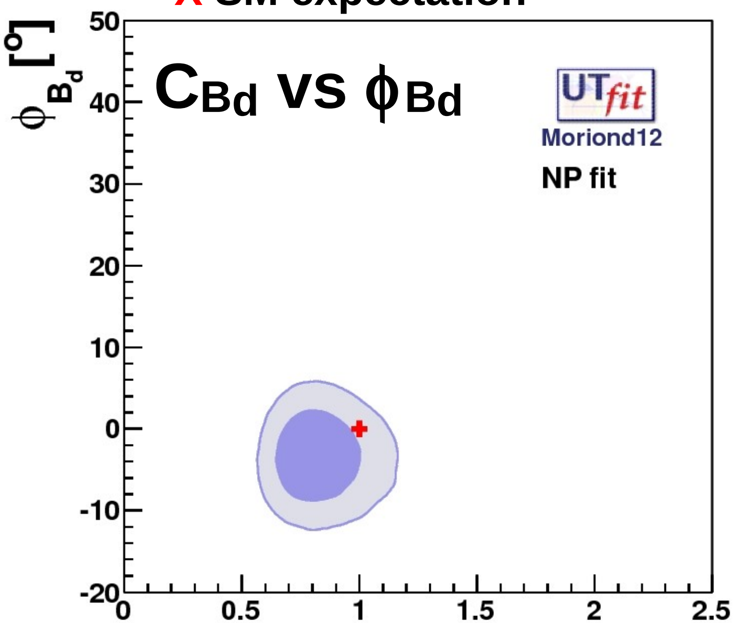
$C_{\varepsilon_K} = 0.99 \pm 0.17$

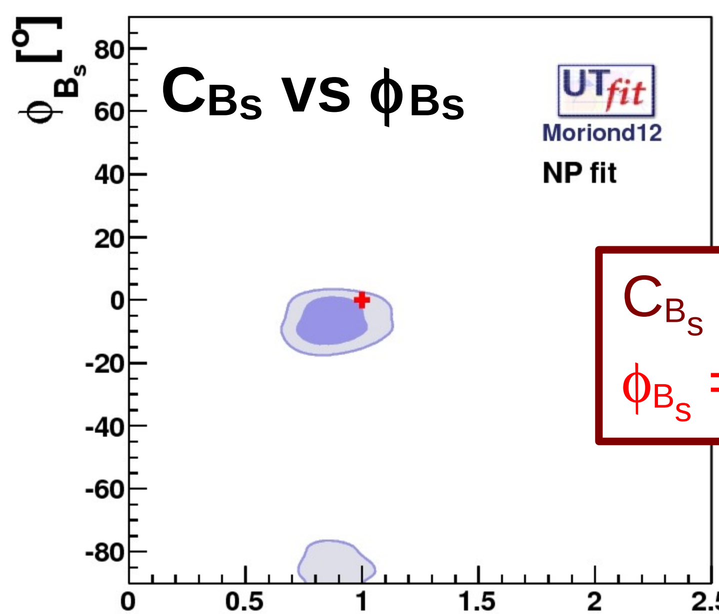
$C_{\Delta mK} = 0.97 \pm 0.33$

$C_{B_d} = 0.81 \pm 0.12$

$\phi_{B_d} = (-3.4 \pm 3.6)°$

X SM expectation





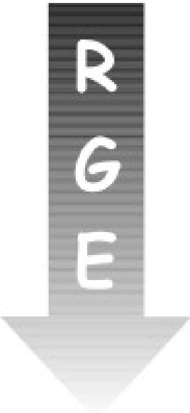
$C_{B_s} = 0.87 \pm 0.09$

$\phi_{B_s} = (-7 \pm 5)°$

SM at ~1.4σ

SM at ~1.3σ

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

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

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

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

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

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

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

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***, **$\eta = \alpha_s(\Lambda)/\alpha_s(m_t)$**

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

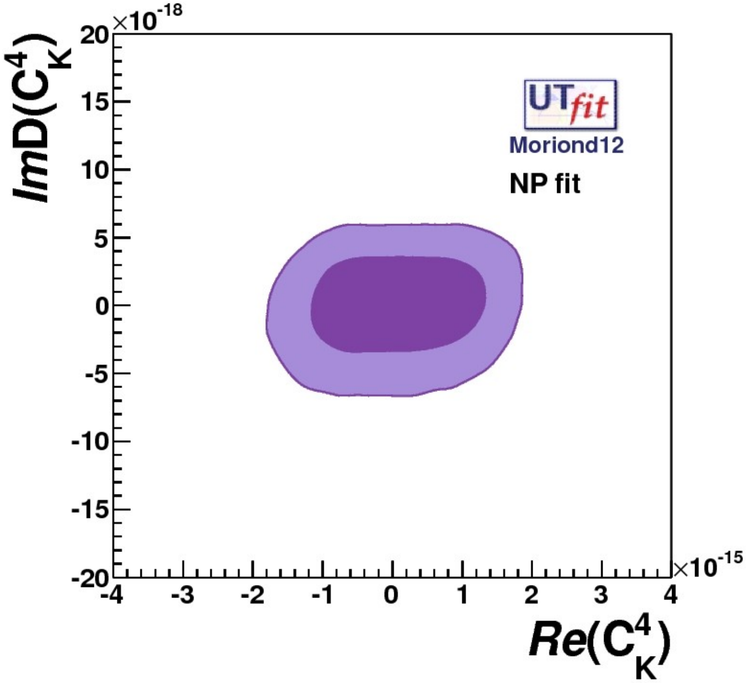
- **$\alpha \sim 1$ for strongly coupled NP**
- **$\alpha \sim \alpha_W$ (α_s) in case of loop coupling through weak (strong) interactions**

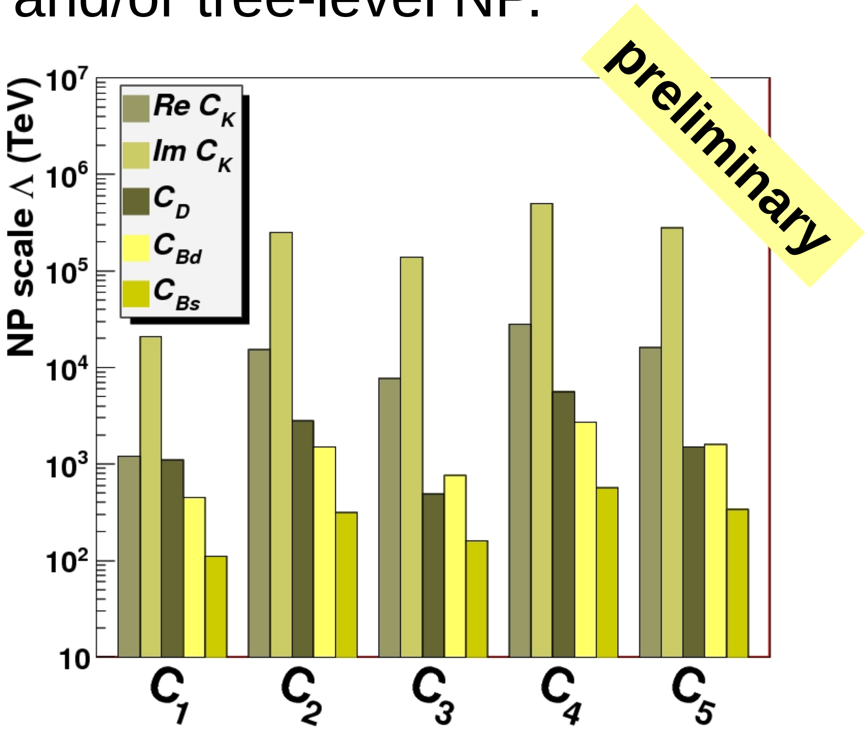
If no NP effect is seen
lower bound on NP scale Λ
if NP is seen
upper bound on NP scale Λ

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 $L_i = 1$, corresponding to strongly-interacting and/or tree-level NP.





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).

Scenario	strong/tree	α_s loop	α_W loop
NMFV	19	1.9	0.6
General	27000	2700	900

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

conclusions

- SM analysis displays good overall consistency but some tension in sin2β, B_k and $B\rightarrow\tau\nu$
- Extraction of SM predictions with different scenarios: still open discussion on semileptonic inclusive vs exclusive
- General UTA provides a precise determination of CKM parameters and NP contributions to $\Delta F=2$ amplitudes

backup

Lattice QCD parameters

current

$B_K = 0.731 \pm 0.036$
$f_{Bs} = 0.250 \pm 0.012$
$f_{Bs}/f_{Bd} = 1.215 \pm 0.019$
$B_s/B_d = 1.05 \pm 0.07$
BBs1 = 0.87 ± 0.04

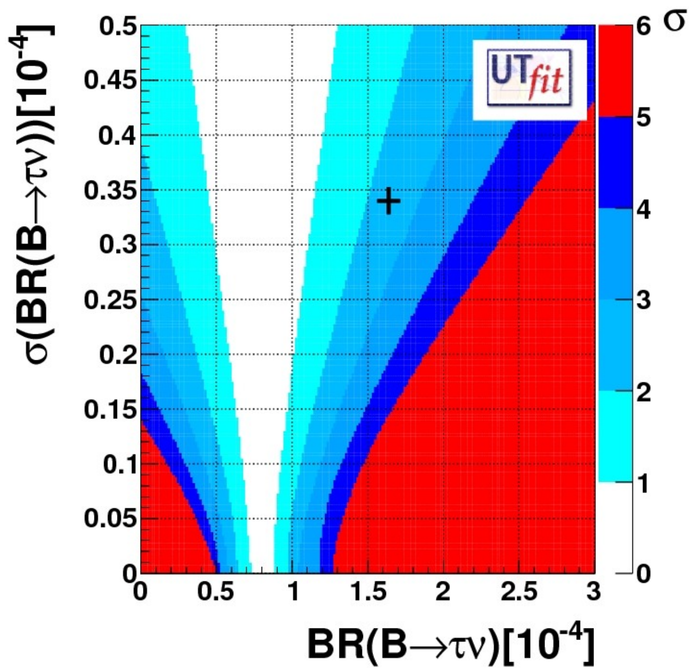
running update

$B_K = 0.750 \pm 0.020$
$f_{Bs} = 0.233 \pm 0.010$
$f_{Bs}/f_{Bd} = 1.200 \pm 0.020$
$B_s/B_d = 1.05 \pm 0.07$
BBs1 = 0.87 ± 0.04

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

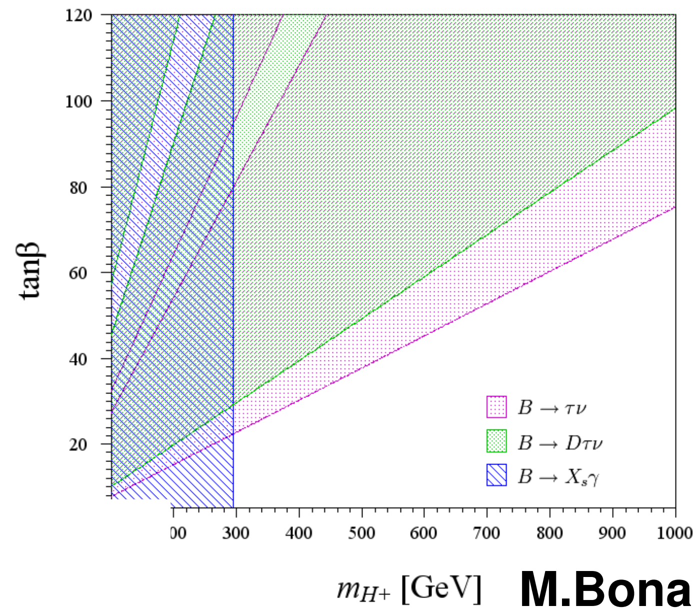
current HFAG world average
BR(B→τν) = (1.64 ± 0.34) 10^{-4}

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



SM prediction enhanced or reduced by factor r_H:

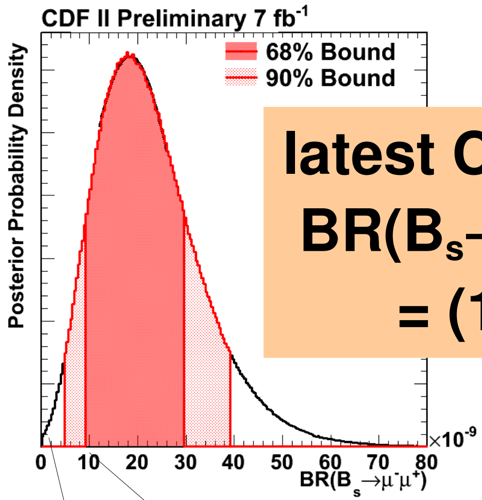
$$R_{2HDM} = \left(1 - \tan^2\beta \frac{m_B^2}{m_{H^+}^2}\right)^2$$



indirect determination from UT_b
BR(B→τν) = (0.79 ± 0.08) 10^{-4}

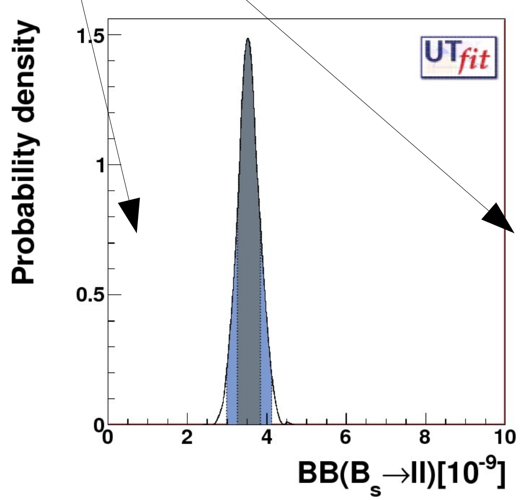
M.Bona et al 0908.3470 [hep-ph]

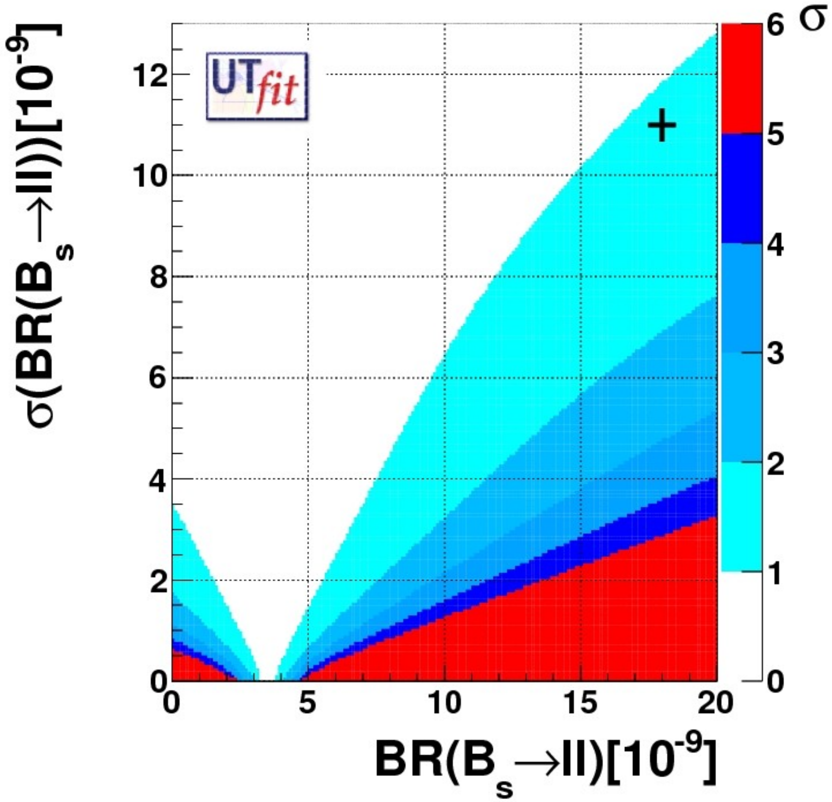
more standard model determinations: $B_s \to \mu\mu$



latest CDF result:

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



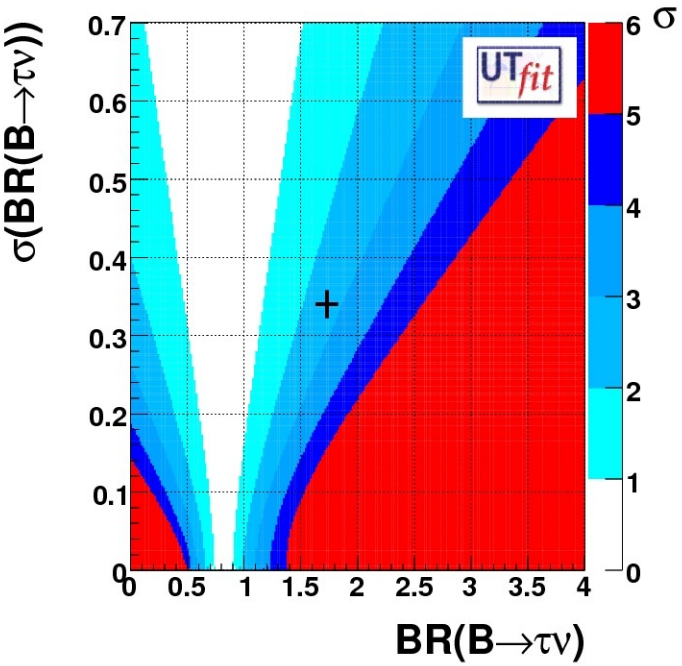


indirect determination from UT

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

$B \to \tau\nu$

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

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

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

~2.7σ

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

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)

$B \to \tau\nu$

Consider Two Higgs Doublet model II

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

$\to$ **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
$BR(B\to D\tau\nu)/BR(B\to D\ell\nu) = (49\pm10)\%$

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

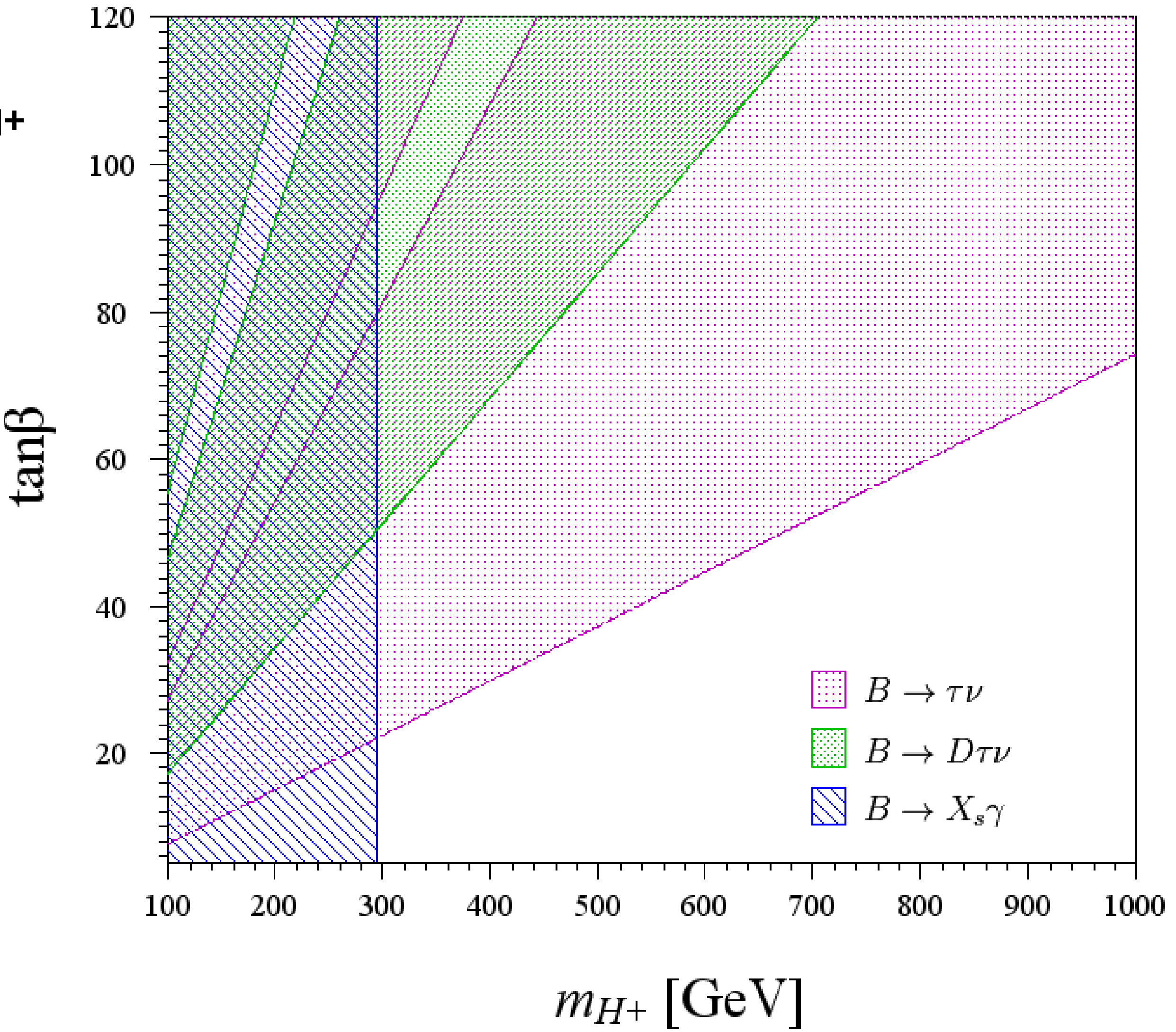
B→τν

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

Consider Two Higgs Doublet model II

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

→ **bounds on tanβ/m_{H+}**



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