Unitarity Triangle Analysis and Searches for New Physics

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UTfit

- Status of the Standard Model Analysis
- UT beyond the SM and constraints on NP:
  - Minimal Flavour Violation: UUT, $B \to \tau\nu$, ...
  - Beyond MFV: NP scales, B_s mixing, ...
- Conclusions and Outlook

http://www.utfit.org

INTRODUCTION

- 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. sin2β, Δm_s, ...)

INTRODUCTION

- NP UT analysis: given some hypothesis on NP (no corr. to SM tree, MFV, NMFV, ...)
  - disentangle possible NP effects: CKM determination, mixing, decay amplitudes
  - provide best CKM determination
  - extract allowed range for NP contributions to $\Delta F=2$ & $\Delta F=1$
  - obtain bounds on NP parameters

CP-CONSERVING INPUT

- $|V_{ub}|/|V_{cb}| \sim R_b$ (tree-level)
  - incl $b \to cl\nu \Rightarrow |V_{cb}|=(41.54 \pm 0.44 \pm 0.58)10^{-3}$,
    $b \to ul\nu \Rightarrow |V_{ub}|=(39.9 \pm 1.5 \pm 4.0)\ 10^{-4}$
    (HFAG + flat error for model spread)
  - excl: $B \to D^{(*)} l\nu \Rightarrow |V_{cb}|=(39.0 \pm 0.9)10^{-3}$,
    $b \to \pi(\rho) l\nu \Rightarrow |V_{ub}|=(35.0 \pm 4.0)\ 10^{-4}$
    using LQCD form factors

Lubicz & Tarantino

CP-CONSERVING INPUT

- $|V_{td}|/|V_{cb}| \sim R_t$ from B_d-$\bar{B}_d$ and B_s-$\bar{B}_s$ mixing (loop mediated):
  - $\Delta m_d = (0.507 \pm 0.005)\ ps^{-1}$
  - $\Delta m_s = (17.77 \pm 0.12)\ ps^{-1}$
  - $f_{Bs}\sqrt{B_{Bs}} = (275 \pm 13)$ MeV
  - $\xi = 1.24 \pm 0.03$

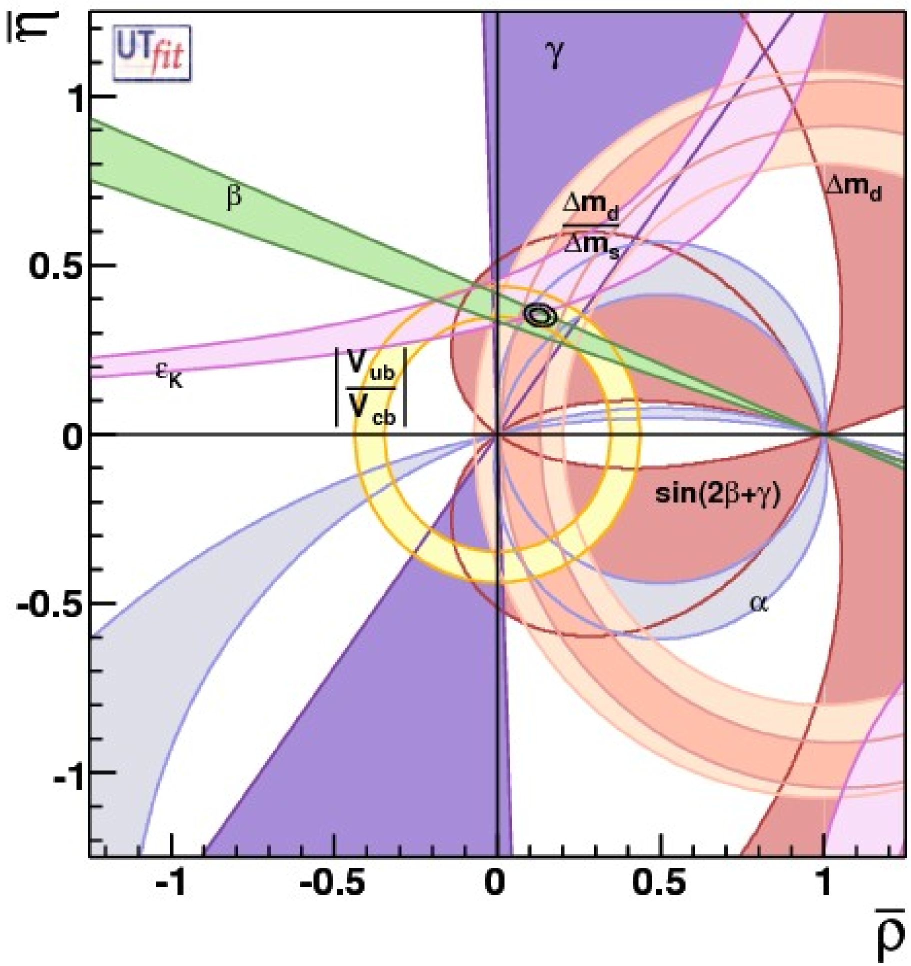
Laiho, Lunghi, V.d.Water

CP-VIOLATING INPUT

- $\sin 2\beta$ from $B \to J/\Psi K$ + th error from CPS:
  $\sin 2\beta = 0.655 \pm 0.027$
- γ combined: $(72 \pm 11)^\circ \cup (-108 \pm 11)^\circ$
- α combined: $(91 \pm 6)^\circ$
- ε_K corrected for measured phase, Im A_0 and LD contributions Buras, Guadagnoli, Isidori
  - F_K=156.0 ± 1.3 MeV, B_K = 0.731 ± 0.036

Lubicz @ Lattice09

RESULTS OF THE SM FIT



$\bar{\rho} = 0.130 \pm 0.020$

$\bar{\eta} = 0.352 \pm 0.013$

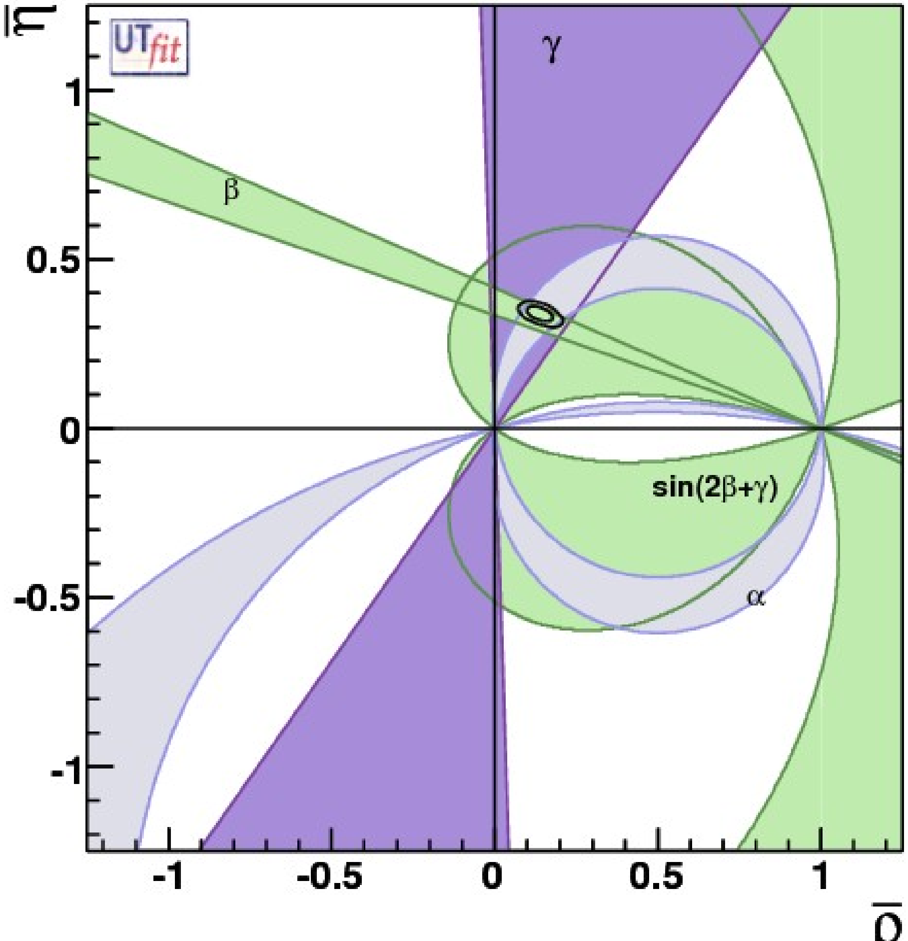
$\beta = (22 \pm 1)^\circ$

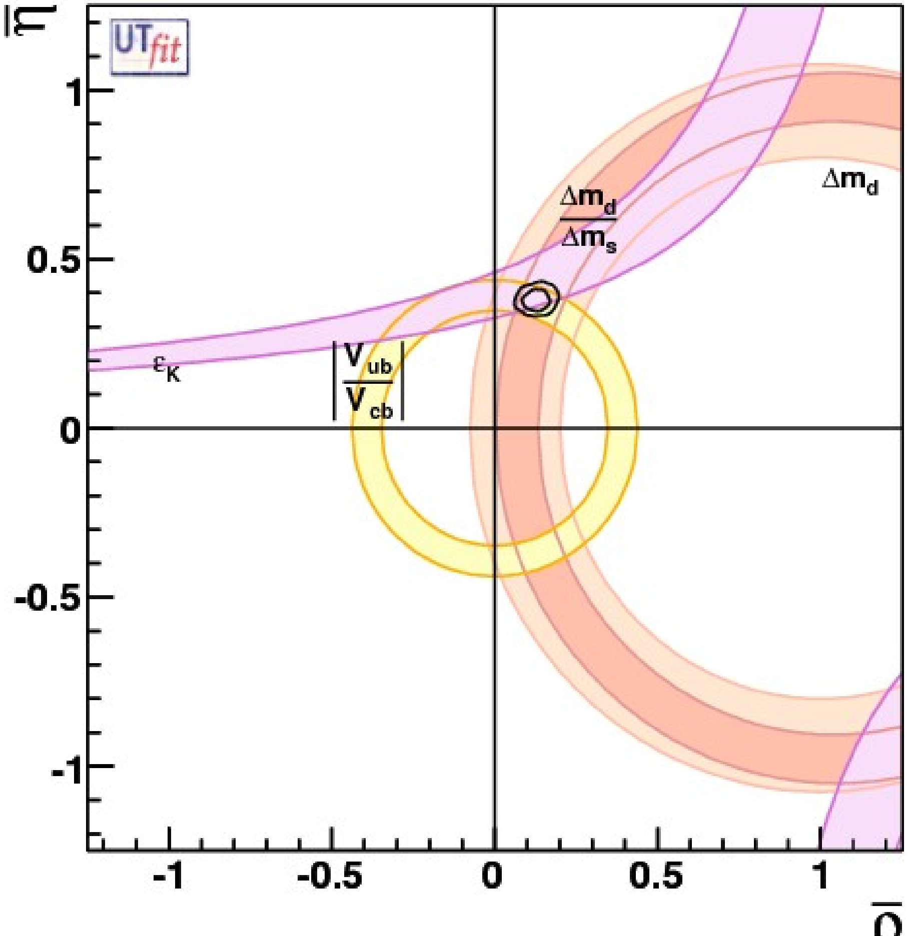
$\gamma = (70 \pm 3)^\circ$

$\alpha = (88 \pm 3)^\circ$

Here and in the following: PRELIMINARY winter 2010 results

ANGLES vs NON-ANGLES





$\bar{\rho} = 0.139 \pm 0.029$ | $\bar{\rho} = 0.129 \pm 0.028$

$\bar{\eta} = 0.338 \pm 0.015$ | $\bar{\eta} = 0.380 \pm 0.021$

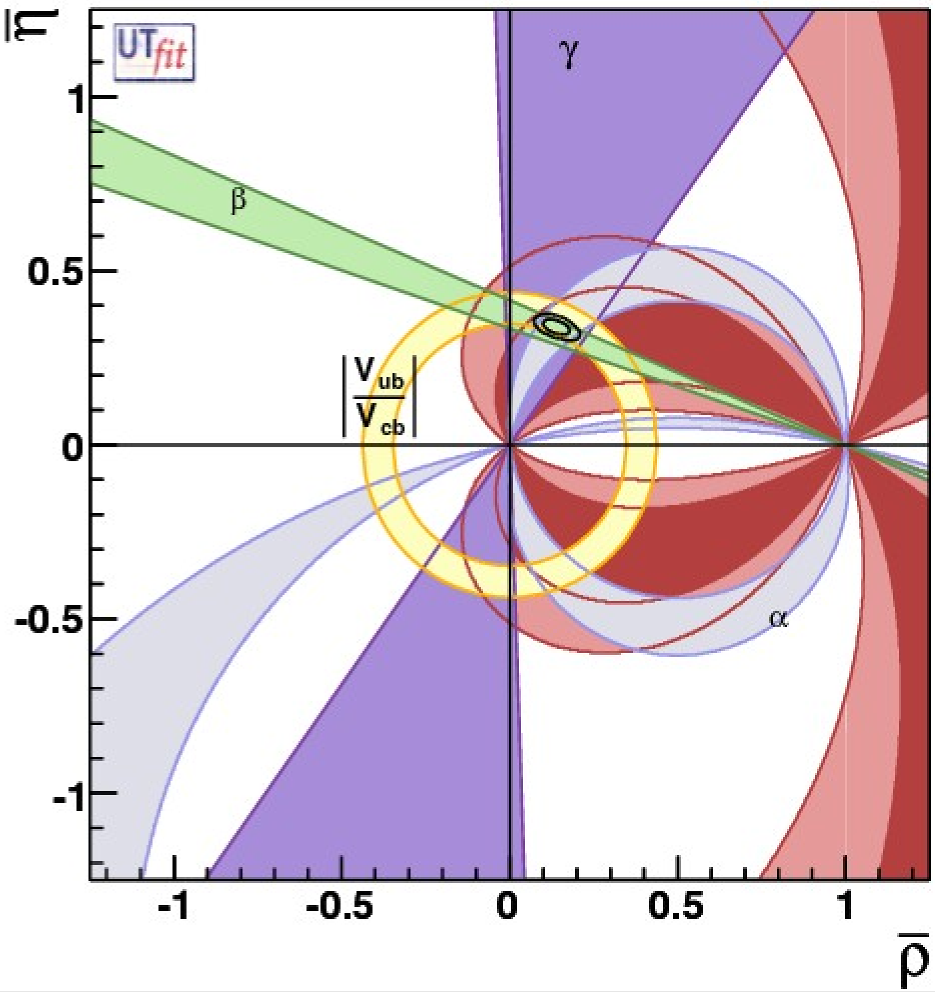
FIT PREDICTIONS vs INPUTS

	Prediction	Measurement	Pull (σ)
$\sin 2\beta$	0.750±0.033	0.655±0.027	2.2
α	(86±4)°	(91±6)°	<1
γ	(69±3)°	(74±11)°	<1
Δm_s	$(17.6\pm1.4)\,ps^{-1}$	$(17.77\pm0.12)\,ps^{-1}$	<1
$\|V_{ub}\|$	$(36\pm1)10^{-4}$	$(38.8\pm2.2)10^{-4}$	1.2
B_K	(0.853±0.070)	(0.731±0.036)	1.5
$BR(B\to\tau\nu)$	$(82\pm8)10^{-6}$	$(174\pm34)10^{-6}$	2.6

THE UUT & MFV MODELS

- Consider MFV models ($Y_{u,d}$ only source of flavour & CPV) D'Ambrosio et al.,...
- Can define a Universal Unitarity Triangle using only observables unaffected by MFV-NP: R_b & angles Buras et al.
- UUT results starting point for model-dependent studies

UUT RESULTS



$\bar{\rho} = 0.138 \pm 0.029$

$\bar{\eta} = 0.339 \pm 0.015$

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

$\gamma = (68 \pm 5)^\circ$

$\alpha = (90 \pm 5)^\circ$

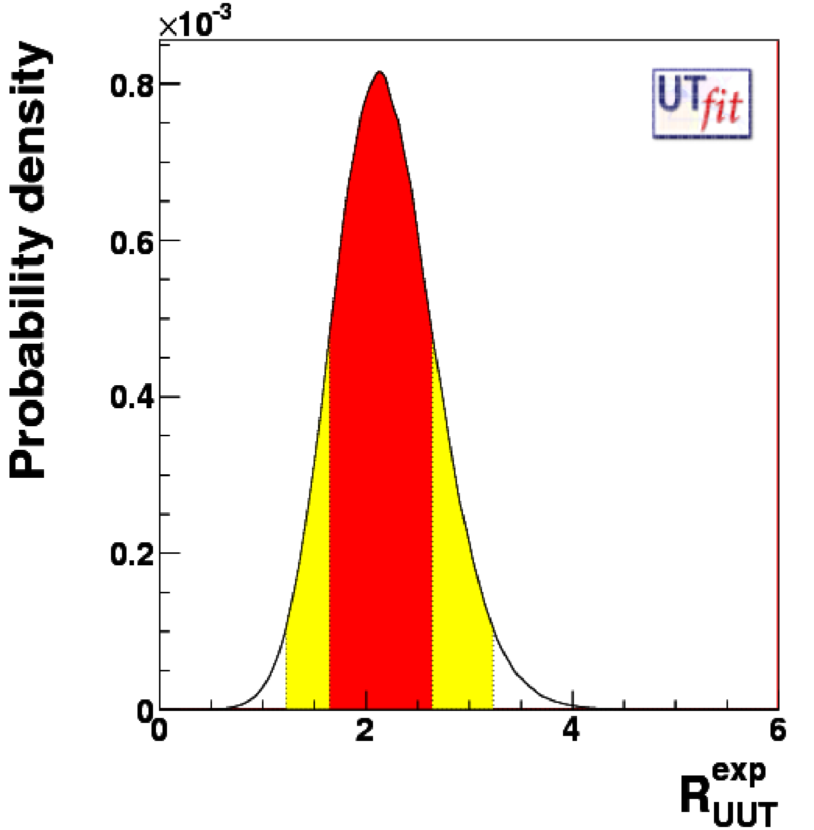
$B \to \tau\nu$ in MFV models

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

We obtain:

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

where $R^{exp}_{UUT} = BR_{exp} / \overline{BR}_{UUT}$ to be compared with the $|V_{ub}|$- and f_B-independent th. calculation of R_{UUT} in specific MFV models



Two Higgs Doublet Model II

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

Two regions selected:

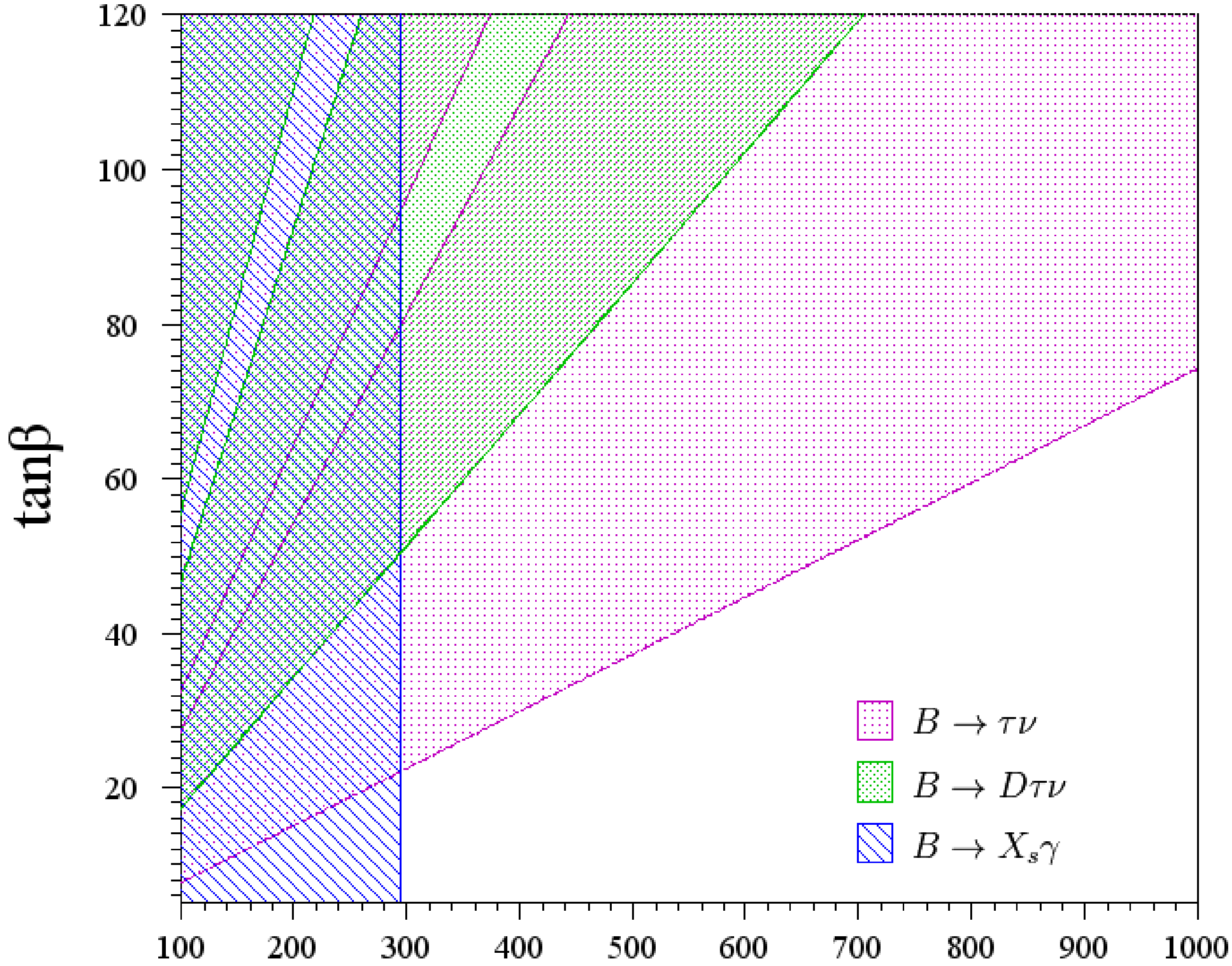
1. small $\tan\beta/m_{H+}$: R < 1 disfavoured at ~2σ

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)%

Iijima @ LP09
Kamenik & Mescia

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

Misiak et al.



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

$$BR(B_s \to \mu^+\mu^-) = (4.3 \pm 0.9) \times 10^{-9}$$

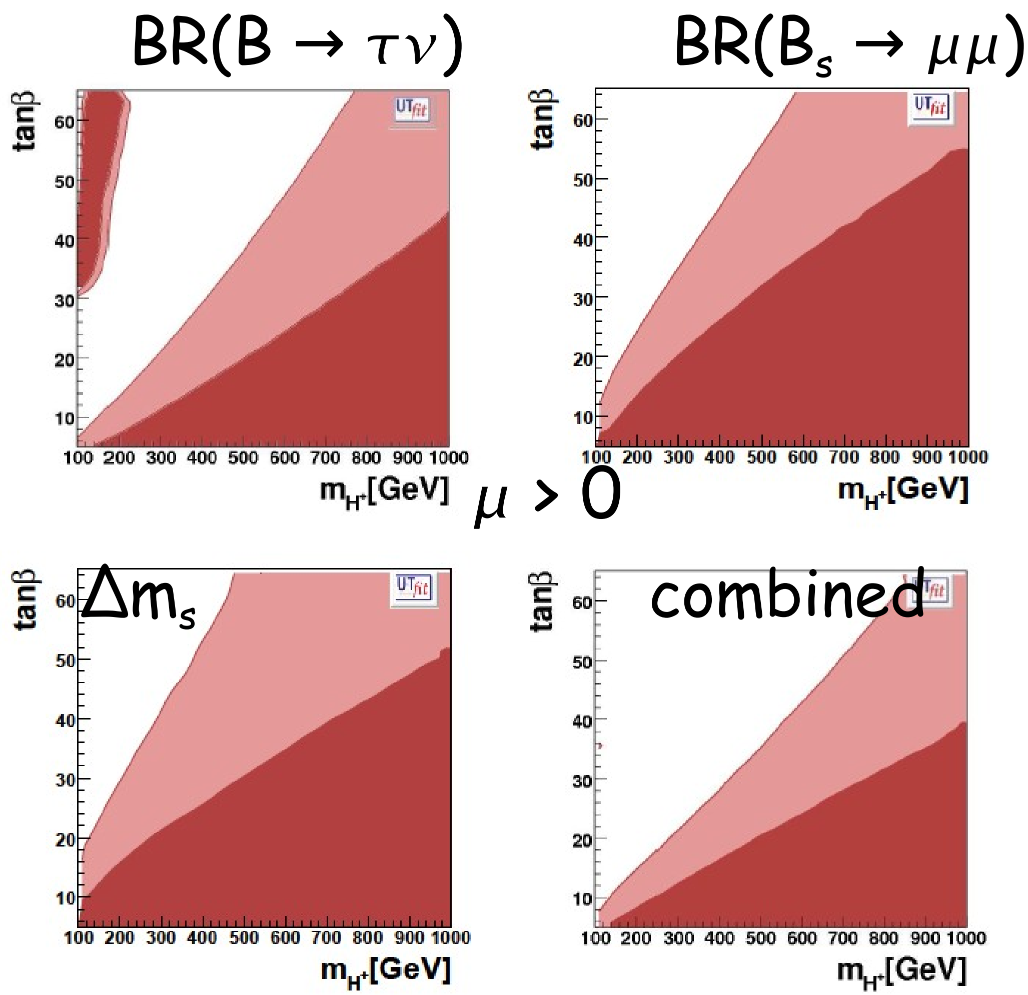
$$([2.5, 6.2] \times 10^{-9} \text{ @95\% prob.})$$

MFV-MSSM at large tanβ

* additional constraints exclude the "fine-tuned" region at very large $\tan\beta$

* bound similar to 2HDM

$$\tan\beta < 7.3 m_{H^+}/(100\ \mathrm{GeV})$$



In addition:

$BR(B_s \to \mu\mu) < 26\times10^{-9}$ @95% prob.

The case μ < 0 is similar…

$$R_{B\tau\nu} = \left[1 - \left(\frac{m_B^2}{m_{H^\pm}^2}\right) \frac{\tan^2\beta}{(1+\epsilon_0 \tan\beta)}\right]^2$$

$$\epsilon_0 = -\frac{2\alpha_s \mu}{3\pi M_{\tilde{g}}} H_2\left(\frac{M^2_{\tilde{q}_L}}{M^2_{\tilde{g}}}, \frac{M^2_{\tilde{d}_R}}{M^2_{\tilde{g}}}\right)$$

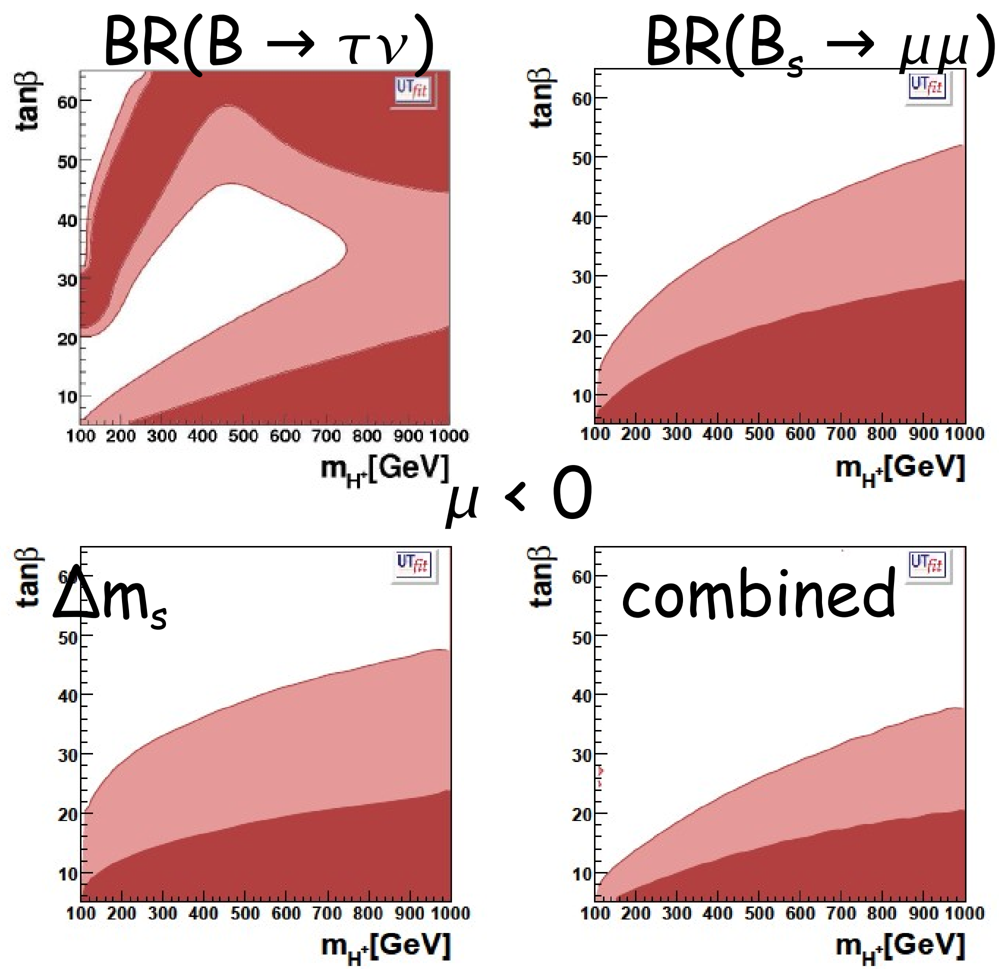
* for μ < 0 the region of positive interference at very large tanβ is enlarged

* yet the combined bound is stronger than for μ > 0

tanβ < 38 @95% prob.

In this case:

BR($B_s \to \mu\mu$) < 17x10^{-9} @95% prob.



UTfit beyond 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

Soares, Wolfenstein; Deshpande, Dutta, Oh; Silva, Wolfenstein; Cohen et al.; Grossman, Nir, Worah; Laplace et al; Ciuchini et al; Ligeti; CKMFitter; UTfit; Botella et al.; Agashe et al.; ...

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

1. Parameterization of generic NP contributions to the mixing amplitudes

K mixing amplitude (2 real parameters):

$$\mathrm{Re}\,A_K = C_{\Delta m_K}\,\mathrm{Re}\,A_K^{SM} \qquad \mathrm{Im}\,A_K = C_\varepsilon\,\mathrm{Im}\,A_K^{SM}$$

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:

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

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

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

A FEW REMARKS

- The value of $C_{\varepsilon K}$ extracted from the analysis potentially contains a mixture of $\Delta F=1$ & $\Delta F=2$ NP contributions
- For the B_s analysis, we use an improved theoretical prediction for $\Delta\Gamma$:
  $\Delta\Gamma_s/\Gamma_s=0.14\pm0.02$

  Ciuchini et al., in preparation; see also Lenz & Nierste

  and allow for NP penguin effects in Γ_{12}

RESULTS OF GENERALIZED UTA

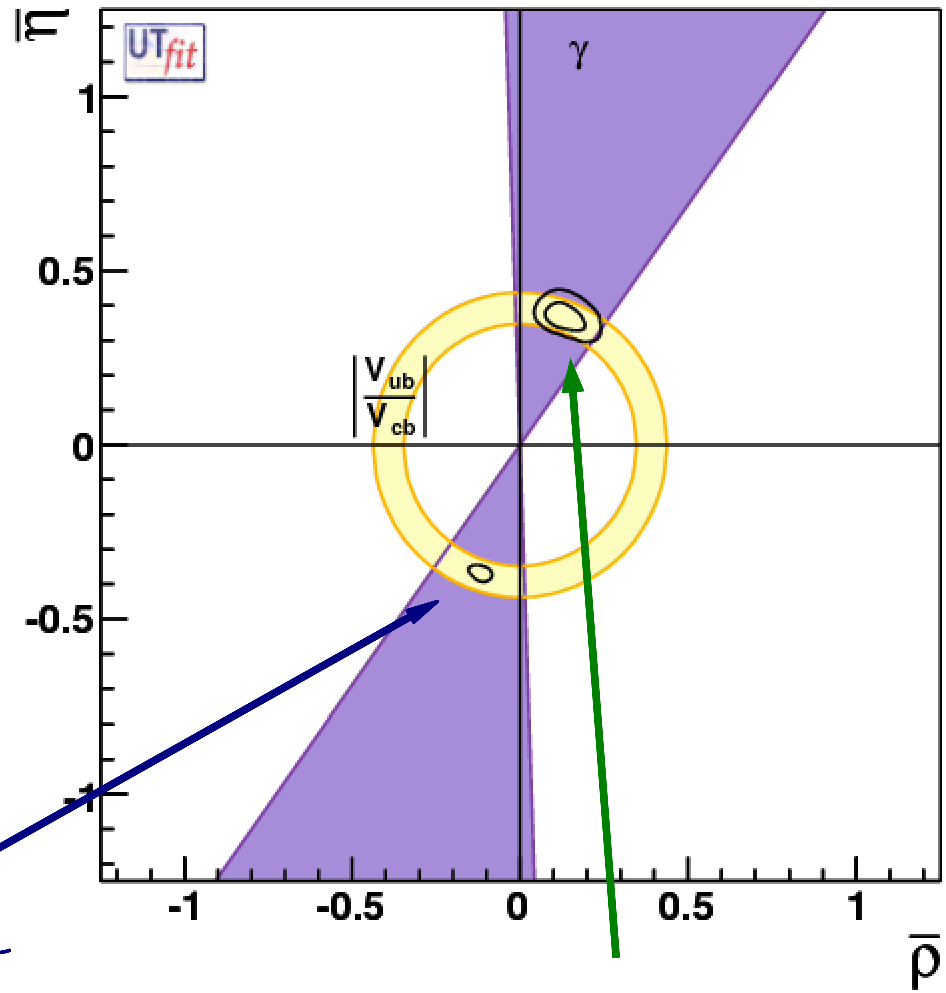
$\bar{\rho} = 0.130 \pm 0.038$

$\bar{\eta} = 0.367 \pm 0.025$

in the SM was:

$\rho = 0.130 \pm 0.020$

$\eta = 0.352 \pm 0.013$



degeneracy of γ broken by A_{SL}

Accuracy improved by α (assuming no huge NP contribution to EWP)

Results for NP parameters:

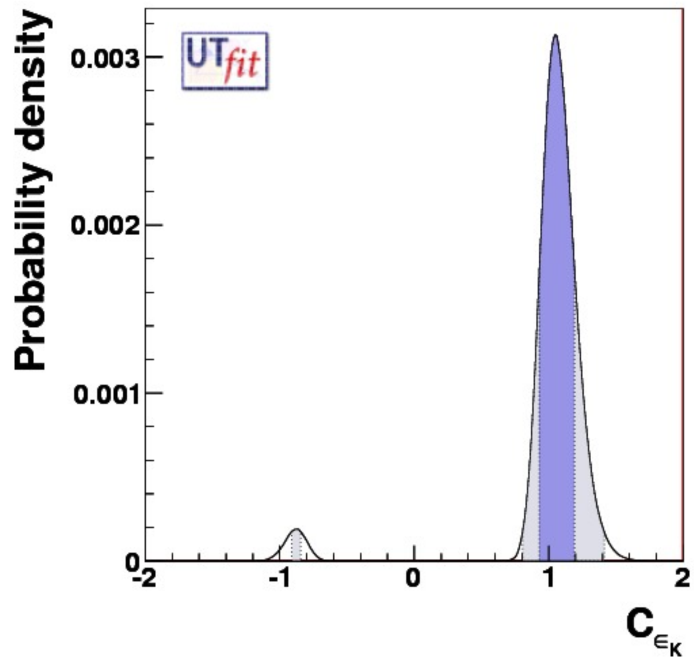
$C_{\varepsilon K}$ = 1.06 ± 0.13 [0.81,1.41]

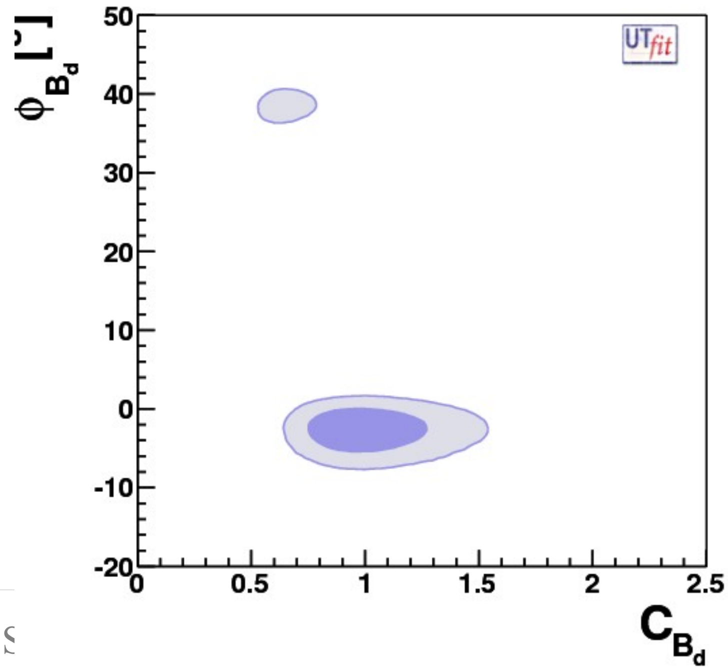
C_{Bd} = 0.99 ± 0.18 [0.64,1.41]

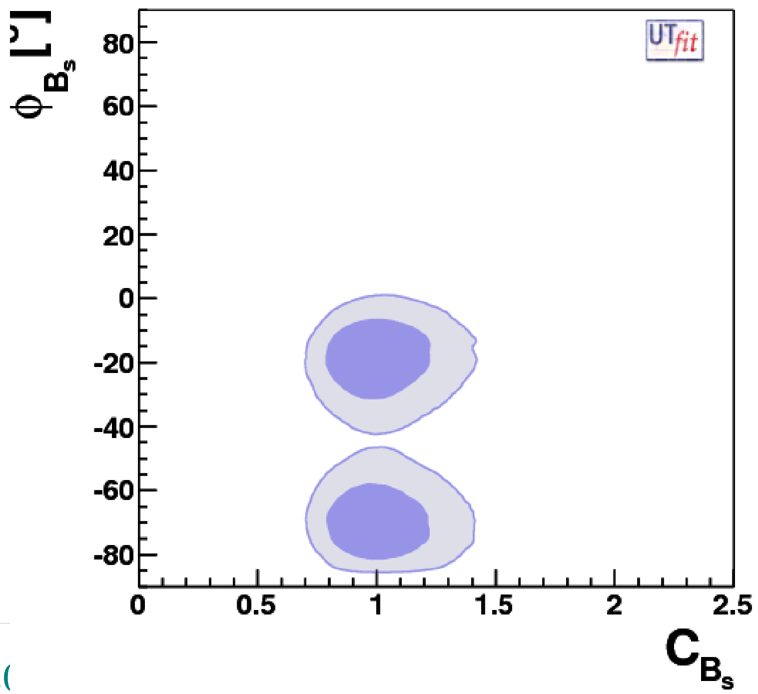
ϕ_{Bd} = (-2.6 ± 1.8)° [-7.3,1.4]°

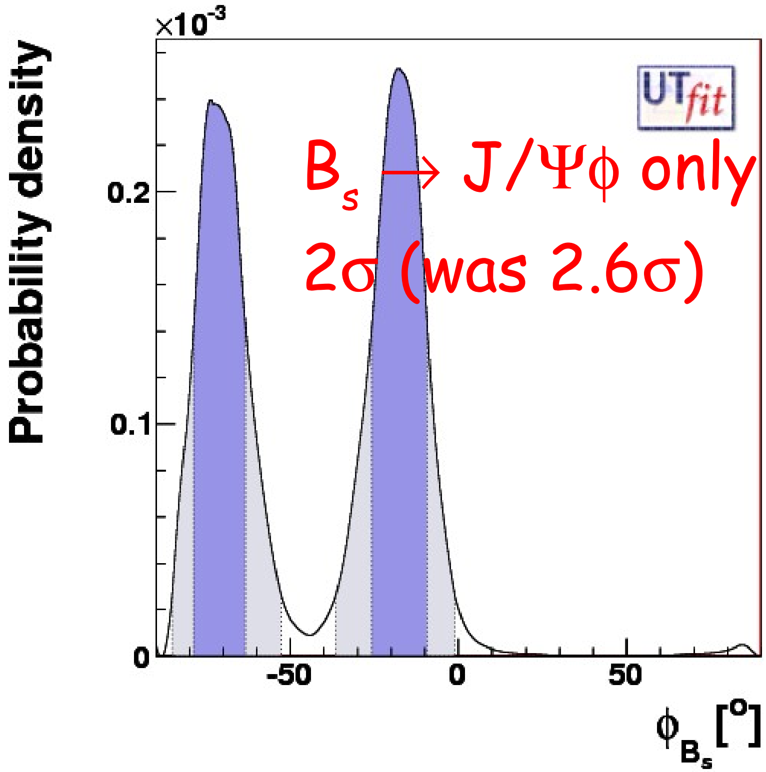
C_{Bs} = 1.00 ± 0.14 [0.75,1.33]

ϕ_{Bs} = (-18 ± 8)° U (-70 ± 8)° [-36,-2]°U[-85,-53]°

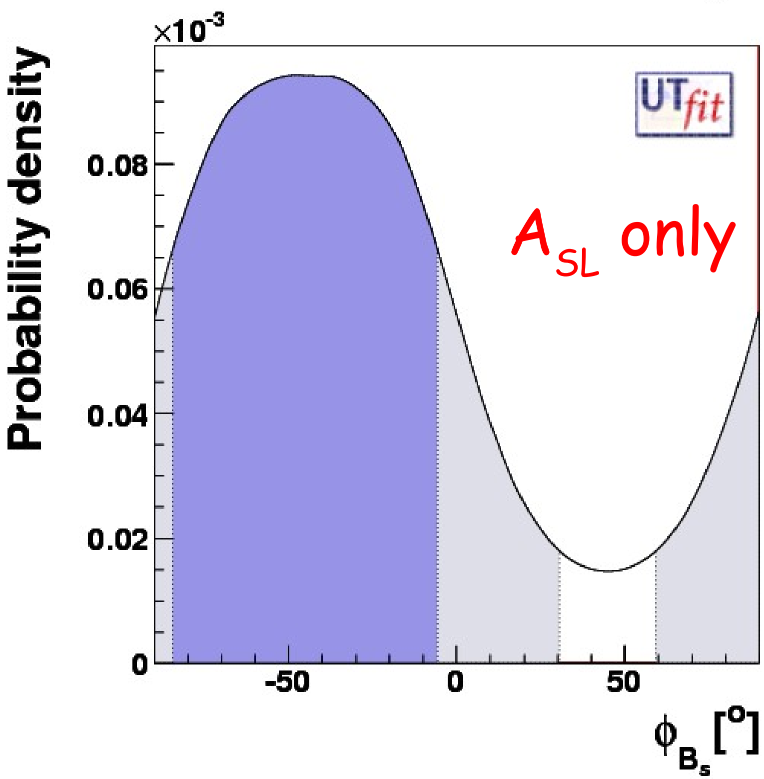


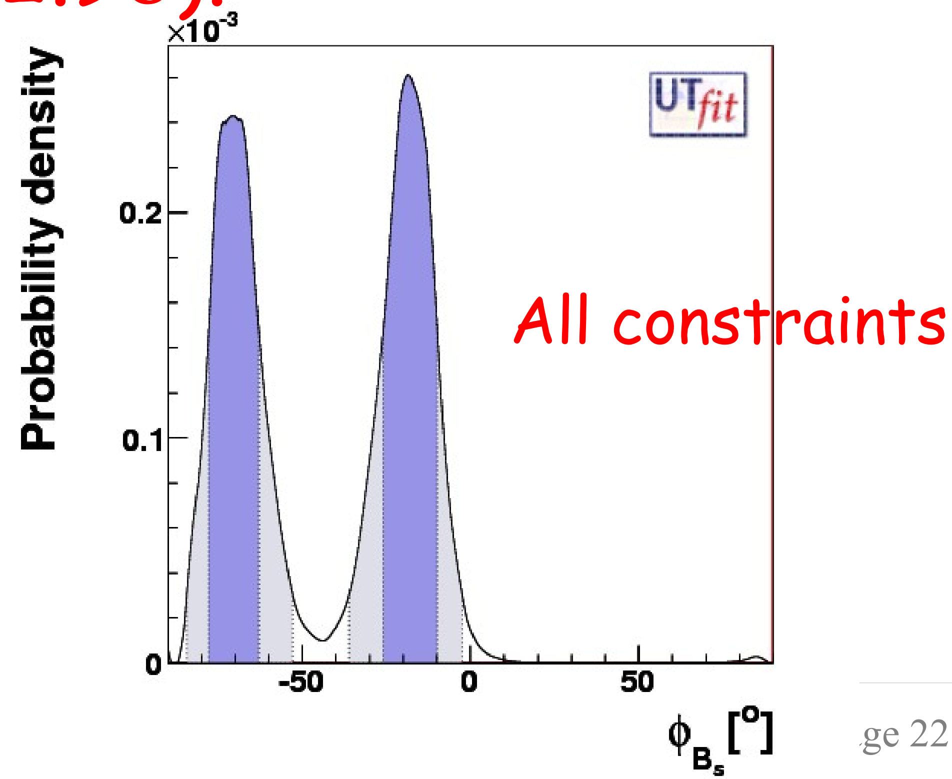


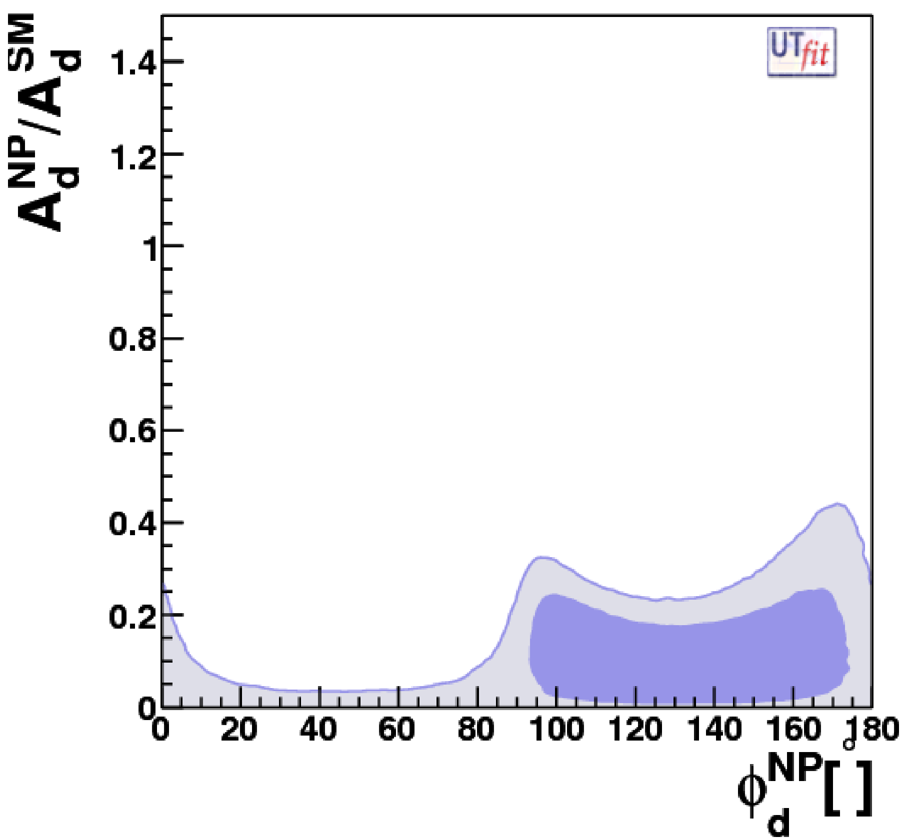


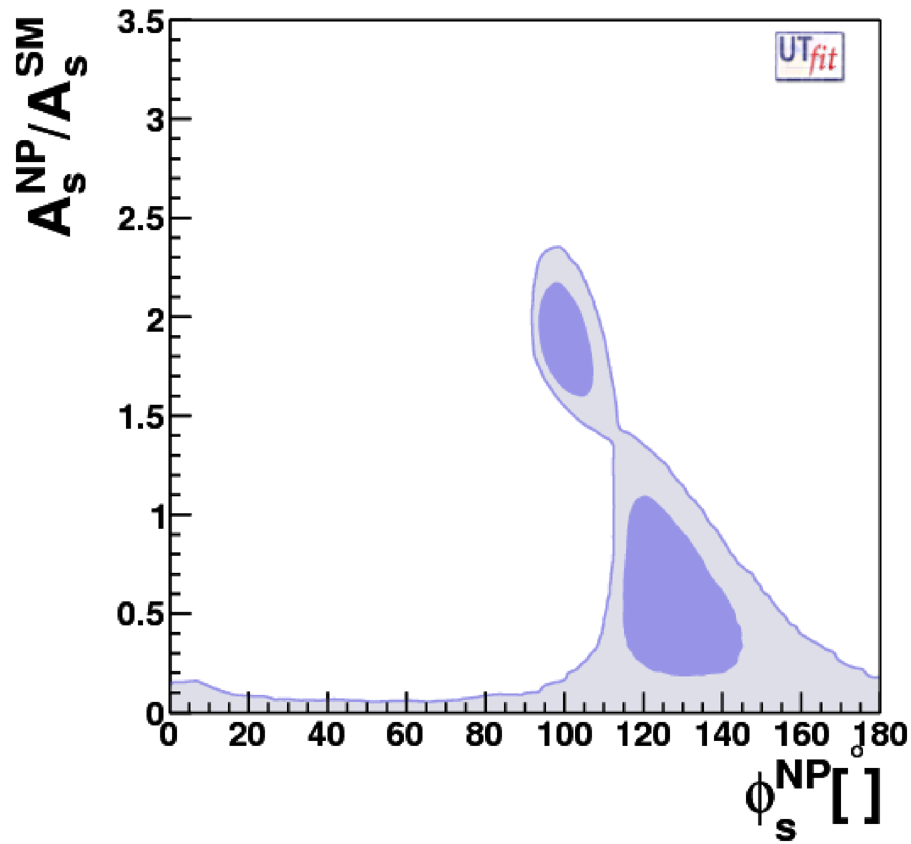


We now use the combined TeVatron likelihood including frequentistic analysis of systematic errors (w. ~20 parameters varied at ±5σ). Using all data we are at 2.4σ (was 2.9σ).









Ratio of NP/SM contributions is < 40% @ 95% prob. in B_d mixing, and ~60% in B_s mixing (but 2σ range is very large)

See also Lunghi & Soni, Buras et al.

- Large NP contributions to $b \leftrightarrow s$ transitions are natural in nonabelian flavour models, given the large breaking of flavour SU(3) due to the top quark mass

Pomarol, Tommasini; Barbieri, Dvali, Hall; Barbieri, Hall; Barbieri, Hall, Romanino; Berezhiani, Rossi; Masiero et al; …

- GUTs can naturally connect the large mixing in ν oscillations with a large $b \leftrightarrow s$ mixing Baek et al.; Moroi; Akama et al.; Chang, Masiero, Murayama; Hisano, Shimizu; Goto et al.; …

- Might show up also in $\Delta F=1$ transitions ($b\to s\gamma$, $b\to sl^+l^-$, $B\to K\pi$, $B_s\to K^{*0}K^{*0}$, ...) and/or LFV ($\tau\to\mu\gamma$, $\mu\to e\gamma$)

2. EFT analysis of ΔF=2 transitions

The mixing amplitudes $A_q e^{2i\phi_q} = \langle \bar{M}_q | H_{eff}^{\Delta F=2} | M_q \rangle$

$$H_{eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i(\mu) Q_i(\mu) + \sum_{i=1}^{3} \tilde{C}_i(\mu) \tilde{Q}_i(\mu)$$

$$Q_1 = \bar{q}_L^\alpha \gamma_\mu b_L^\alpha \, \bar{q}_L^\beta \gamma^\mu b_L^\beta \quad \text{(SM/MFV)}$$

$$Q_2 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_R^\beta b_L^\beta \qquad Q_3 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_R^\beta b_L^\alpha$$

$$Q_4 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad Q_5 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_L^\beta b_R^\alpha$$

$$\tilde{Q}_1 = \bar{q}_R^\alpha \gamma_\mu b_R^\alpha \, \bar{q}_R^\beta \gamma^\mu b_R^\beta$$

$$\tilde{Q}_2 = \bar{q}_L^\alpha b_R^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad \tilde{Q}_3 = \bar{q}_L^\alpha b_R^\beta \, \bar{q}_L^\beta b_R^\alpha$$

7 new operators beyond MFV involving quarks with different chiralities

H_{eff} can be recast in terms of the $C_i(\Lambda)$ computed at the NP scale

- $C_i(\Lambda)$ can be extracted from the data (one by one)
- the associated NP scale Λ can be defined from

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

tree/strong interact. NP: $L \sim 1$

perturbative NP: $L \sim \alpha_s^2, \alpha_W^2$

Flavour structures:

MFV	next-to-MFV	generic
- $F_1 = F_{SM} \sim (V_{tq} V_{tb}^*)^2$	- $\vert F_i \vert \sim F_{SM}$	- $\vert F_i \vert \sim 1$
- $F_{i \neq 1} = 0$	- arbitrary phases	- arbitrary phases

present lower bound on the NP scale (TeV):

Process	C_4 (GeV^{-2})	Λ_{GEN} (TeV)	Λ_{NMFV} (TeV)
ε_K	$1.8\ 10^{-17}$	$24\ 10^4$	62
B_d	$1.\ 10^{-13}$	$3.2\ 10^3$	20
B_s	$1.5\ 10^{-11}$	$2.6\ 10^2$	8

* $\Delta F=2$ chirality-flipping operators are RG enhanced and thus probe larger NP scales
* when these operators are allowed, the NP scale is easily pushed beyond the LHC reach
* suppression of the 1 <-> 2 transitions strongly weakens the lower bounds

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 $B\to\tau\nu$ disfavored by present data: 2HDM & MFV-MSSM @ large tanβ

CONCLUSIONS

- General UTA provides a precise determination of CKM parameters and NP contributions to $\Delta F=2$ amplitudes
- ε_K and B_d mixing give strong constraints on NP contributions, naively pushing the NP scale of several models beyond the LHC reach

CONCLUSIONS

- CPV in B_s mixing off from SM at ~2.5σ
- Requires new sources of flavour & CPV, natural in many extensions of the SM
- Theoretical uncertainty negligible now (and in the future if central value confirmed)
- Wait for confirmation from TeVatron/LHCb, look for other NP signals in b→s transitions