Probing the TeV scale (and above) with Flavor Physics

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CERN-PH UTfit Collaboration

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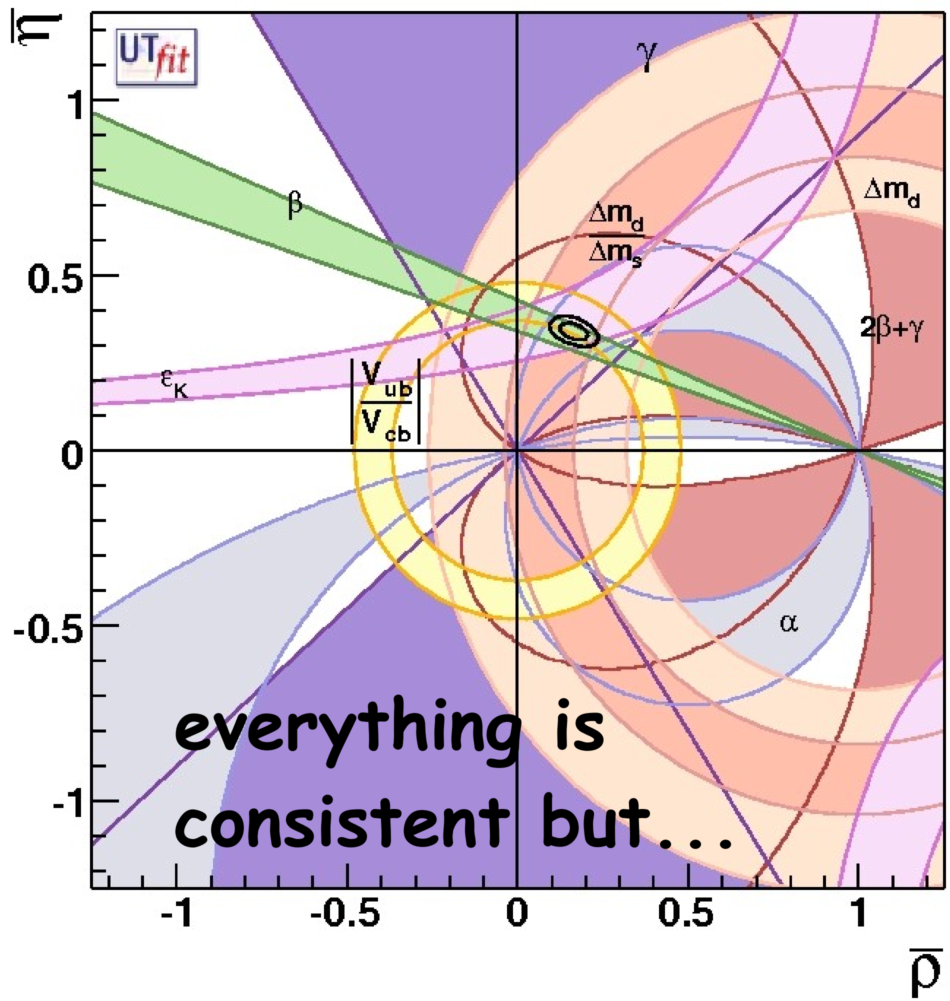
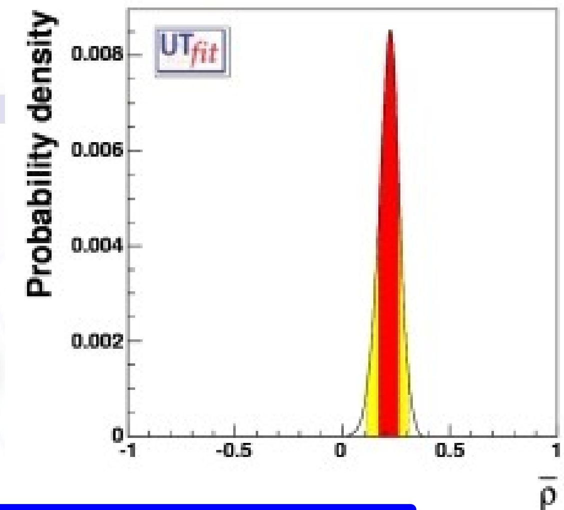
www.utfit.org

JHEP 0603:080,2006 [hep-ph/0509219]
Phys.Rev.Lett.97:151803,2006 [hep-ph/0605213]
arXiv:0707.0636 [hep-ph]

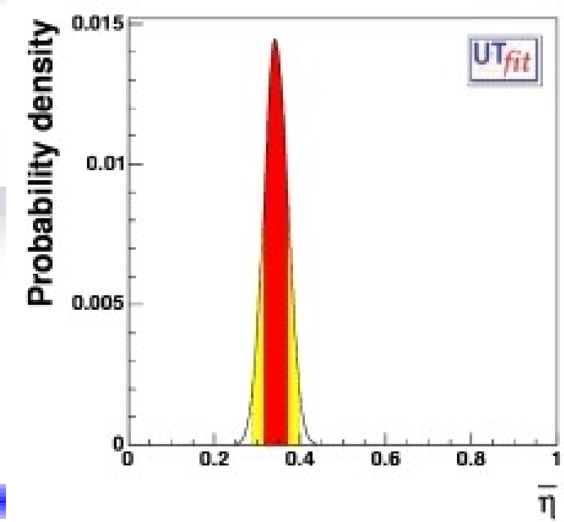
The UTfit in the Standard Model

$\bar{\rho} = 0.164 \pm 0.029$
[0.107, 0.222] @ 95% Prob.





$\bar{\eta} = 0.340 \pm 0.017$
[0.307, 0.373] @ 95% Prob.



NP effects should be there

The SM works beautifully up to a few hundred GeV's, but if it is an effective theory valid up to a scale $\Lambda < M_{planck}$

$$\mathcal{L}(M_W) = \Lambda^2 H^\dagger H + \lambda (H^\dagger H)^2 + \mathcal{L}^{gauge}_{SM} + \mathcal{L}^{Yukawa}_{SM} + \mathcal{L}^5/\Lambda + \mathcal{L}^6/\Lambda^2$$

EW scale

g-2, $b \to s\gamma$, etc

NP contribution to EW precision, FCNC processes, CPV, etc.

Subject of this talk

Gauge hierarchy problem: $\Lambda \sim$ TeV

In general, without deviations from SM in B physics: $\Lambda \sim$ 100-1000 TeV

With the present experimental situation on B-physics side and the expectations of discovery at LHC, there is a "tension" between the NP scales

New Physics and flavor

New Physics scenarios can be classified according to their flavor structure

Generic flavor structure: NP introduces additional complex couplings among quarks (e.g. off-diagonal elements in squark mixing matrix)

Minimal Flavor Violation: CKM is the only source of flavor mixing even beyond SM

- single Higgs doublet or low tanβ: NP enters as a universal correction to K and B_q mixing
- large tanβ: NP enters differently in K and B_q mixing
- very large tanβ: only relevant contribution to B_s mixing

Next-to-Minimal Flavor Violation: NP introduces additional complex couplings among quarks, having the same hierarchy than CKM (same powers of sinθ_C) but arbitrary phase

Using this classification, we will translate the UT bounds into useful information for direct search at LHC

Model independent NP parameters

Consider for example Bd mixing process. Given the SM amplitude, we can define

$$C_{B_d} e^{-2i\phi_{B_d}} = \frac{\langle \overline{B}^0 | H_{eff}^{SM} + H_{eff}^{NP} | B^0 \rangle}{\langle \overline{B}^0 | H_{eff}^{SM} | B^0 \rangle} = 1 + \frac{A_{NP} e^{-21\phi_{NP}}}{A_{SM} e^{-2i\beta}}$$

All NP effects can be parameterized in terms of one complex parameter for each meson mixing, to be determined in a simultaneous fit with the CKM parameters (now there are enough experimental constraints to do so). For Kaons we use Re and Im, since the two exp. constraints ε_K and Δm_K are directly related to them (with different theoretical issues)

How the bounds are modified

model independent assumptions

	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	
$\sin 2\beta$	X	X		
Δm_d	X	X		
α ($\rho\rho,\rho\pi,\pi\pi$)	X	X		
A_{SL} B_d	X	X		
$\Delta\Gamma_d/\Gamma_d$	X	X		
$\Delta\Gamma_s/\Gamma_s$	X			X
Δm_s				X
A_{CH}	X	X		X

SM $\xrightarrow{\text{tree level}}$ **SM+NP**

SM	SM+NP
$(V_{ub}/V_{cb})^{SM}$	$(V_{ub}/V_{cb})^{SM}$
γ^{SM}	γ^{SM}

Bd Mixing

SM	SM+NP
β^{SM}	$\beta^{SM}+\phi_{Bd}$
α^{SM}	$\alpha^{SM}-\phi_{Bd}$
Δm_d	$C_{Bd}\Delta m_d$

Bs Mixing

SM	SM+NP
Δm_s^{SM}	$C_{Bs}\Delta m_s^{SM}$
β_s^{SM}	$\beta_s^{SM}+\phi_{Bs}$

K Mixing

SM	SM+NP
ε_K^{SM}	$C_{\varepsilon K}\,\varepsilon_K^{SM}$
Δm_K^{SM}	$C_{\Delta mK}\,\Delta m_K^{SM}$

J. M. Soares and L. Wolfenstein, Phys. Rev. D 47 (1993) 1021;
N. G. Deshpande *et al.* hep-ph/9608231
J. P. Silva and L.Wolfenstein, hep-ph/9610208
A. G. Cohen *et al.*, hep-ph/9610252]
Y. Grossman, Y. Nir and M. P. Worah, hep-ph/9704287

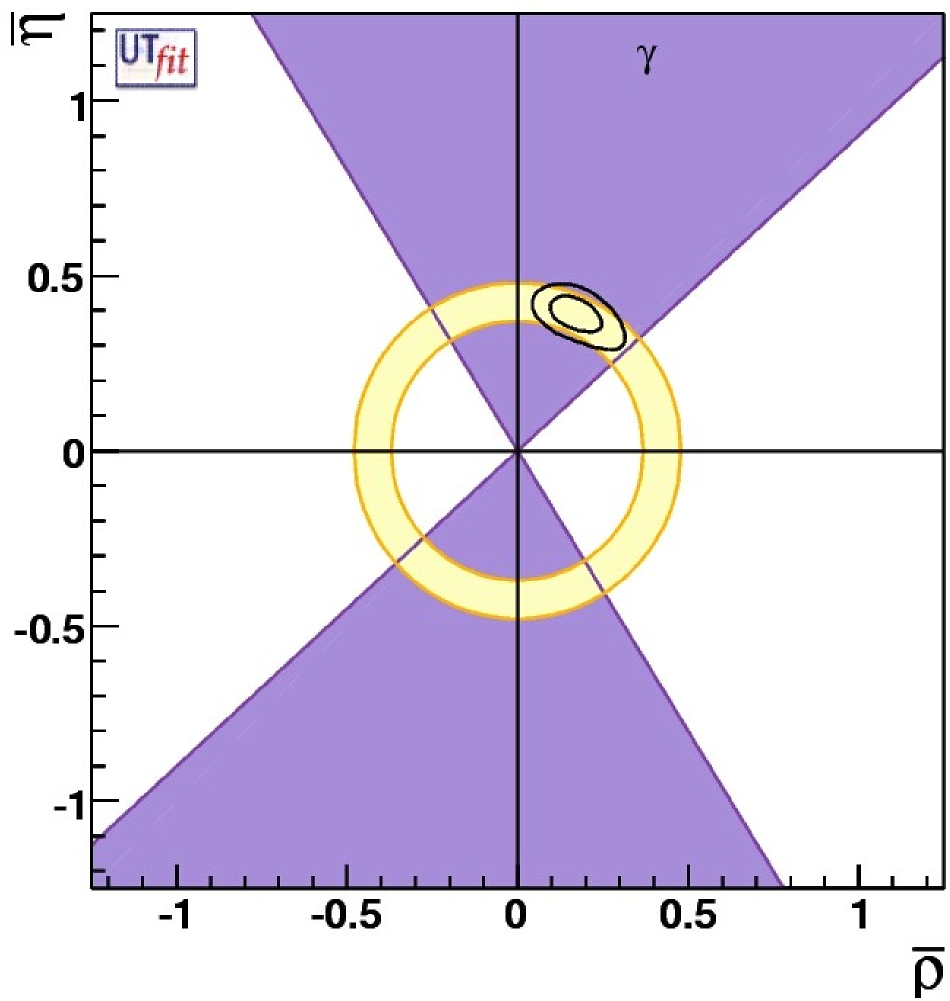
Experimental Inputs

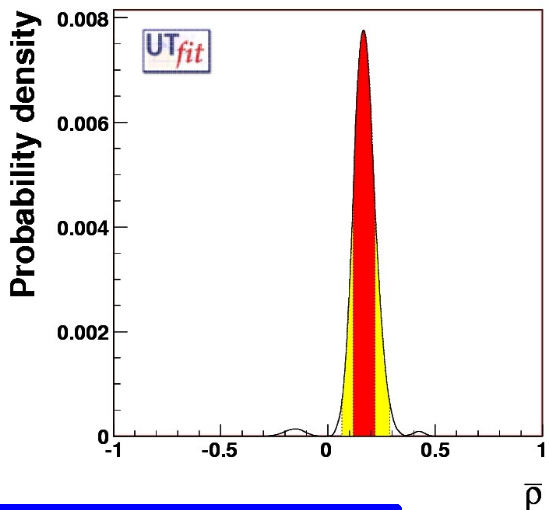
- **For Bd and K sector:**
- same as the SM inputs. See talk by V.Sordini in the Flavor section
- Added A_{SL}^{d}
-
- **For D sector:**
- use the analysis of Ciuchini et al. hep-ph/0703204
- See talk by D. Guadagnoli
-
- **For Bs sector:**
  - Δm_s from CDF
  - $\mathcal{L}(\Delta\Gamma_s, \Gamma_s, \beta_s)$ from D0 (4 ambiguities)
  - $\tau(B_s)$ from flavor specific decays
  - A_{CH} from D0
  - A_{SL}^{s} from D0
-

HFAG averages used

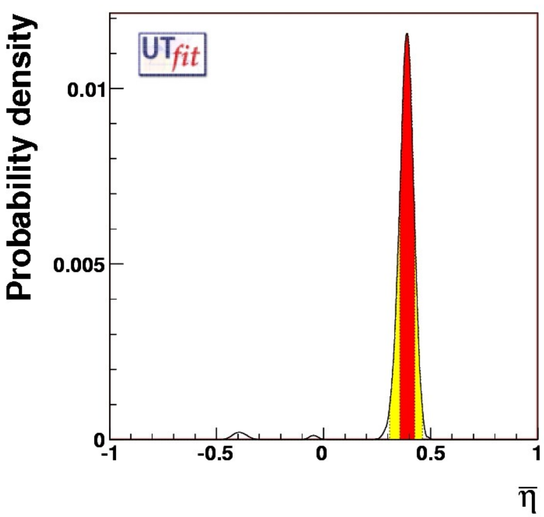
The UTfit allowing New Physics

$\bar{\rho}$ = 0.167 ± 0.051
[0.069, 0.290] @ 95% Prob.



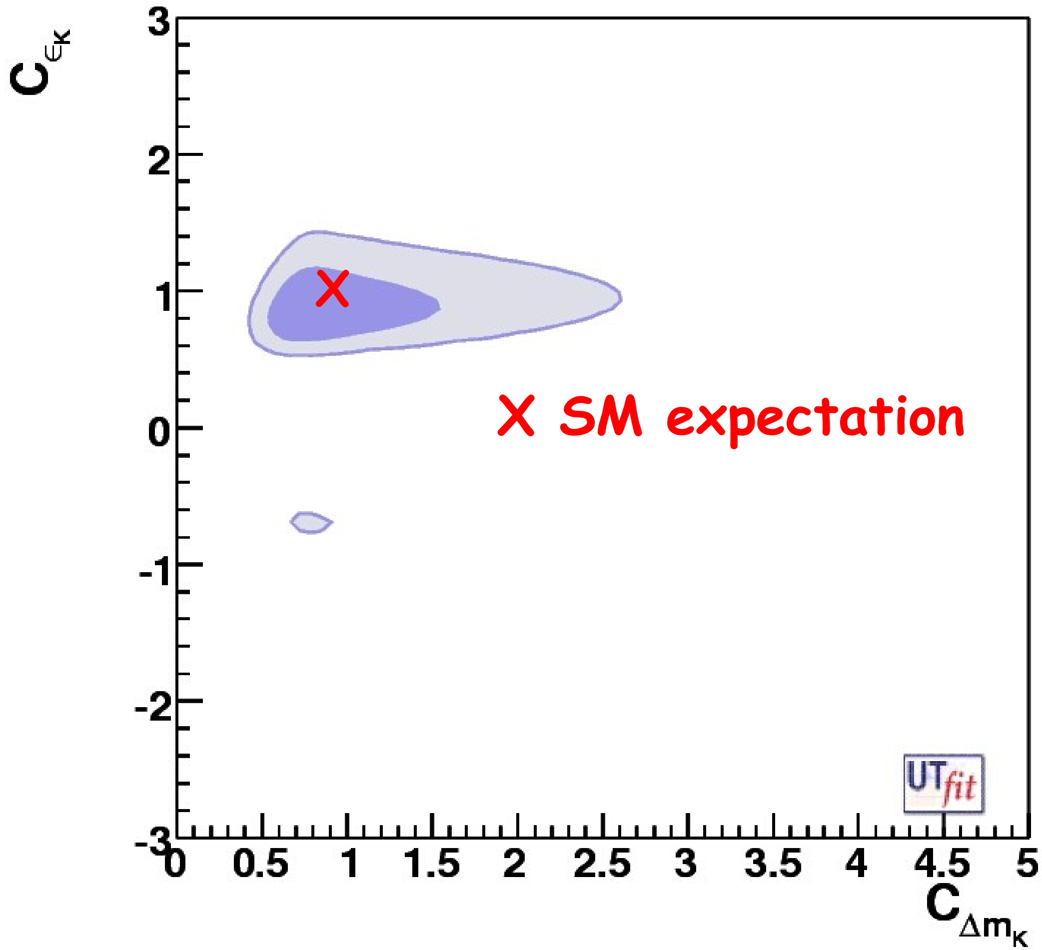


$\bar{\eta}$ = 0.386 ± 0.035
[0.306, 0.459] @ 95% Prob.

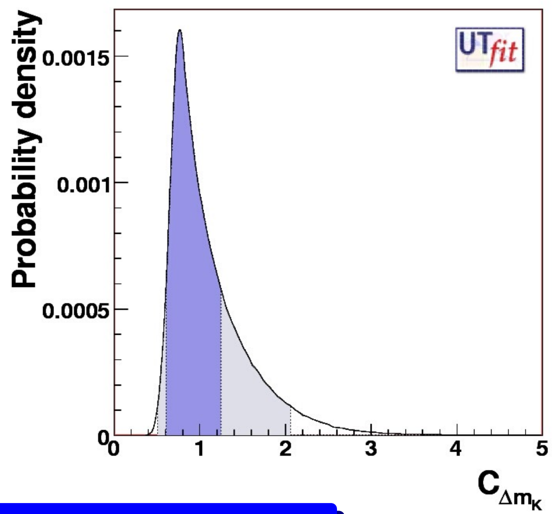


New Physics in the K sector

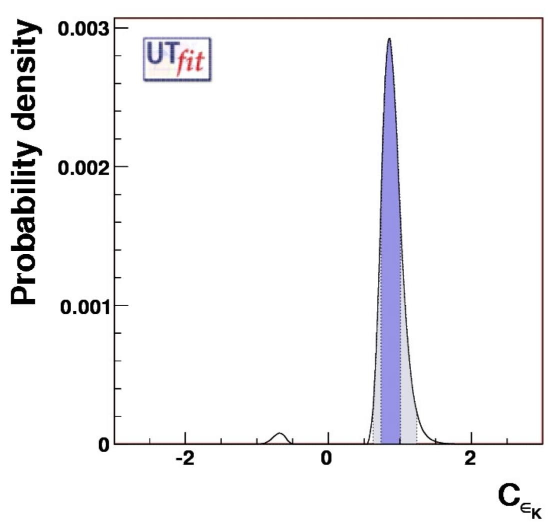
$C_{\Delta mK}$ = 0.93 ± 0.32
[0.51, 2.07] @ 95% Prob.



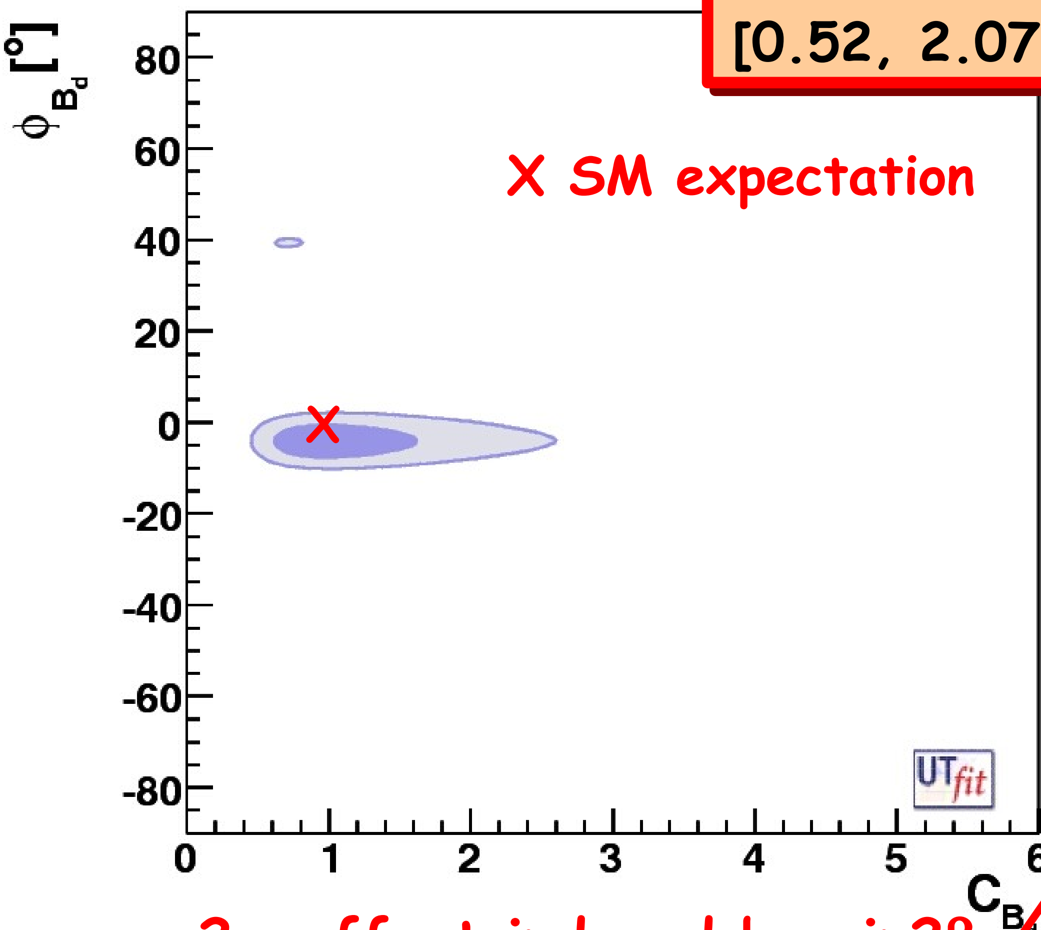
X SM expectation



$C_{\varepsilon K}$=0.88 ± 0.14
[0.63, 1.26] @ 95% Prob.

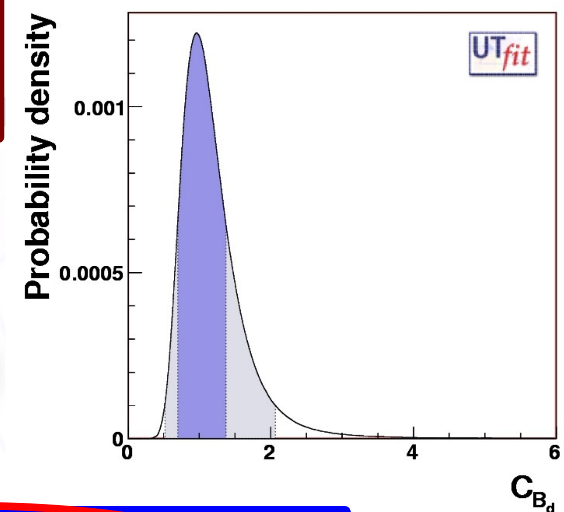


New Physics in the B_d sector

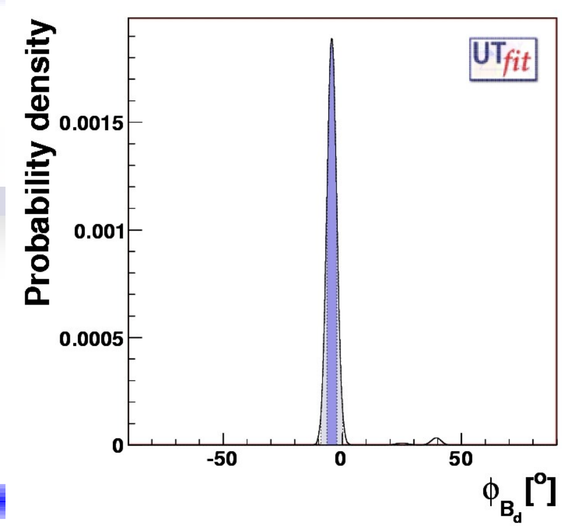


$C_{Bd} = 1.04 \pm 0.34$
[0.52, 2.07] @ 95% Prob.

X SM expectation



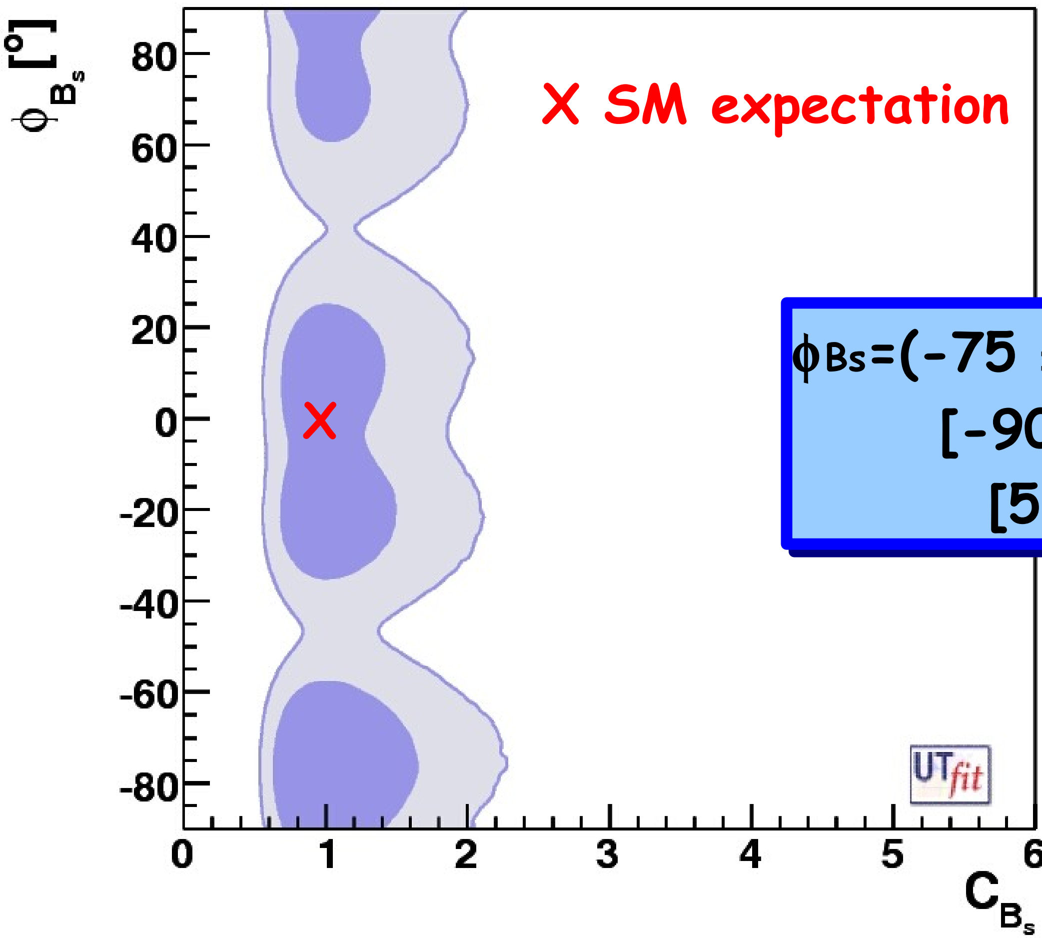
$\phi_{Bd}=(-4.1 \pm 2.1)^{\circ}$
[-8.6°, 0.4°] @ 95% Prob.

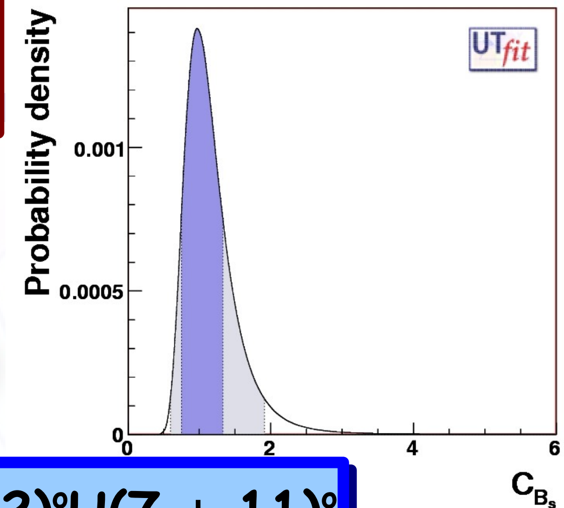


~2σ effect induced by sin2β vs Vub tension Bona et al. JHEP 0603:080,2006 [hep-ph/0509219]

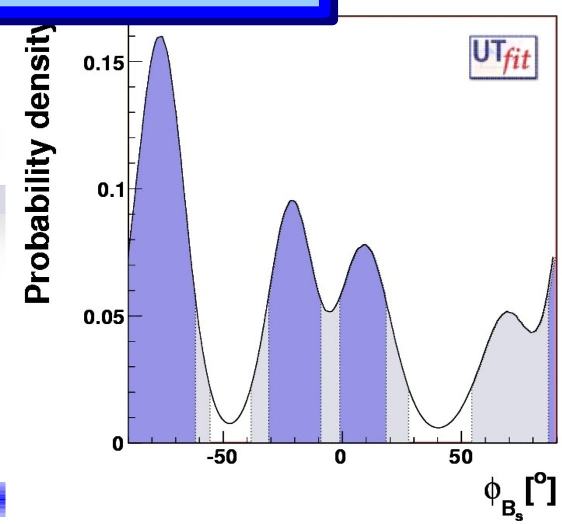
New Physics in the B_s sector

C_{Bs} = 1.04 ± 0.29
[0.60, 1.93] @ 95% Prob.



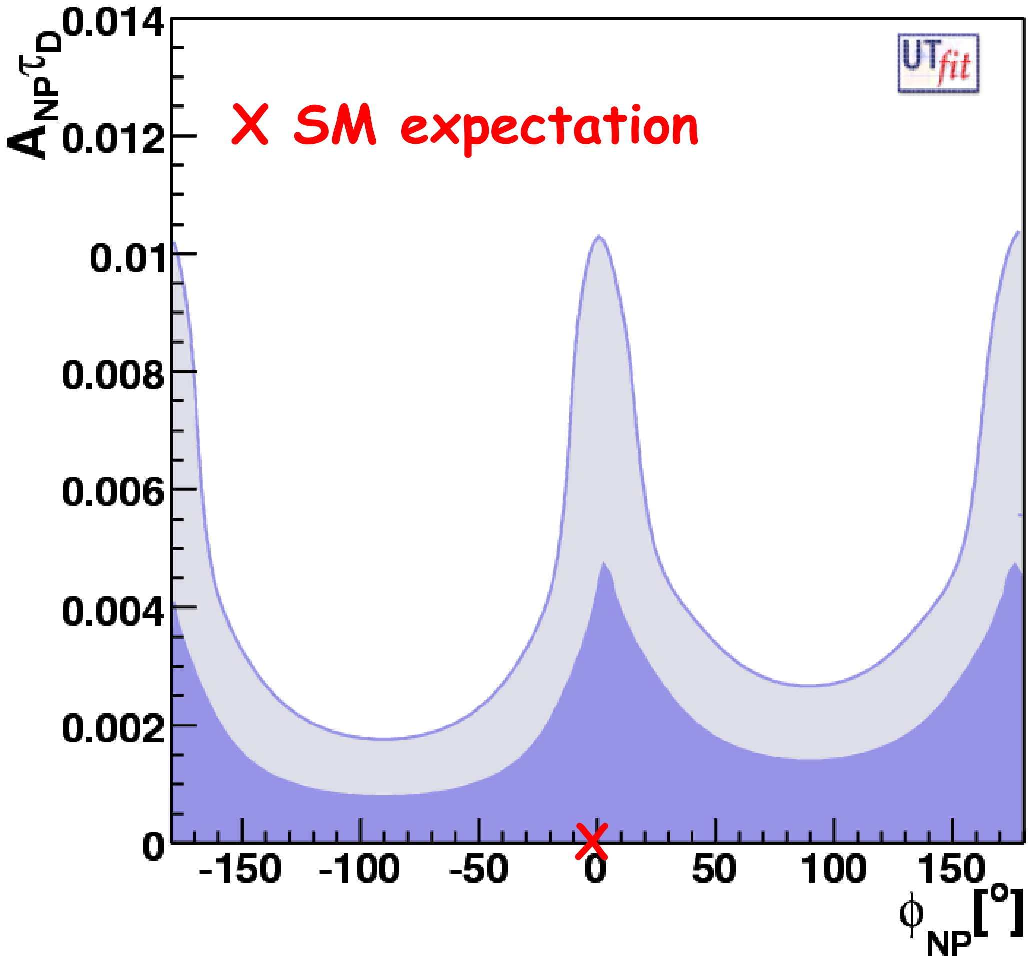


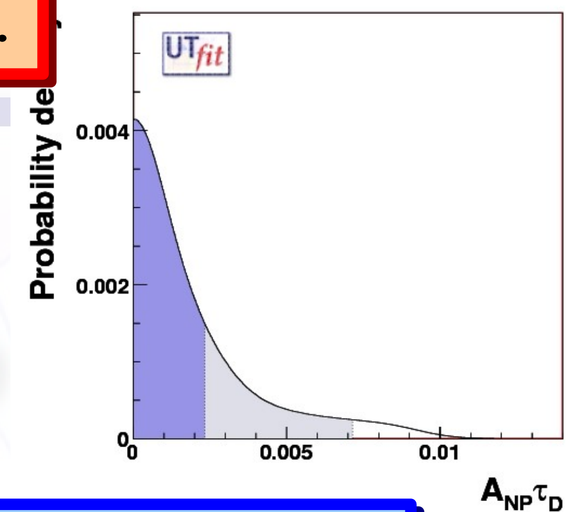
ϕ_{Bs}=(-75 ± 14)°U(-18 ± 12)°U(7 ± 11)°
[-90°, 55°] U [-39°, 30°] U
[55°, 90°]@ 95% Prob.



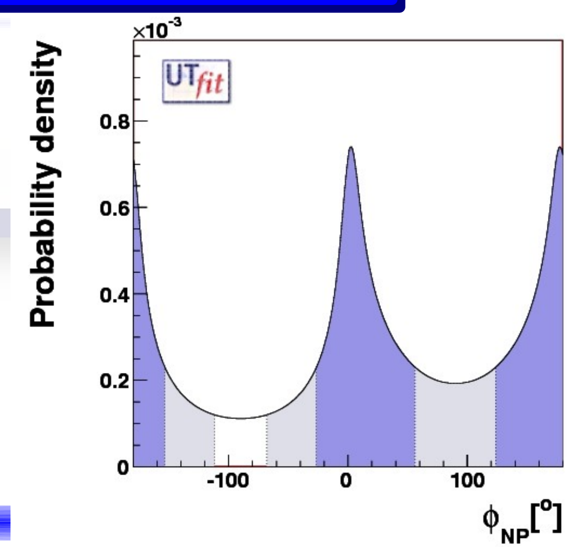
New Physics in the D sector

$A_{NP}\tau_D$ <0.0072 @ 95% Prob.





$\phi_{NP}=(15 \pm 41)°\cup(165 \pm 41)°$
[-68°, 248°] @ 95% Prob.



How NP effects are induced

R
G
E

At the High scale

new physics enters according its specif features (i.e model)

At the Low scale

We can use OPE to write the most general effective Hamiltonian

The operators have different chiralities that 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 the **RGE** that

From Wilson Coeff. to NP Scale (I)

"magic numbers" (see paper) $\eta = \alpha_s(\Lambda)/\alpha_s(m_t)$,

Lattice QCD

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

The dependence of the C on L changes according to flavor structure:

Generic: $C(\Lambda) = a/\Lambda^2$ with arbitrary phase

NMFV: $C(\Lambda) = a \times |F_{SM}|/\Lambda^2$ with arbitrary phase

MFV: $C(\Lambda) = a \times F_{SM}/\Lambda^2$ (i.e. with SM phase)

a is the coupling among NP and SM:

a ~ 1 for strongly coupled NP

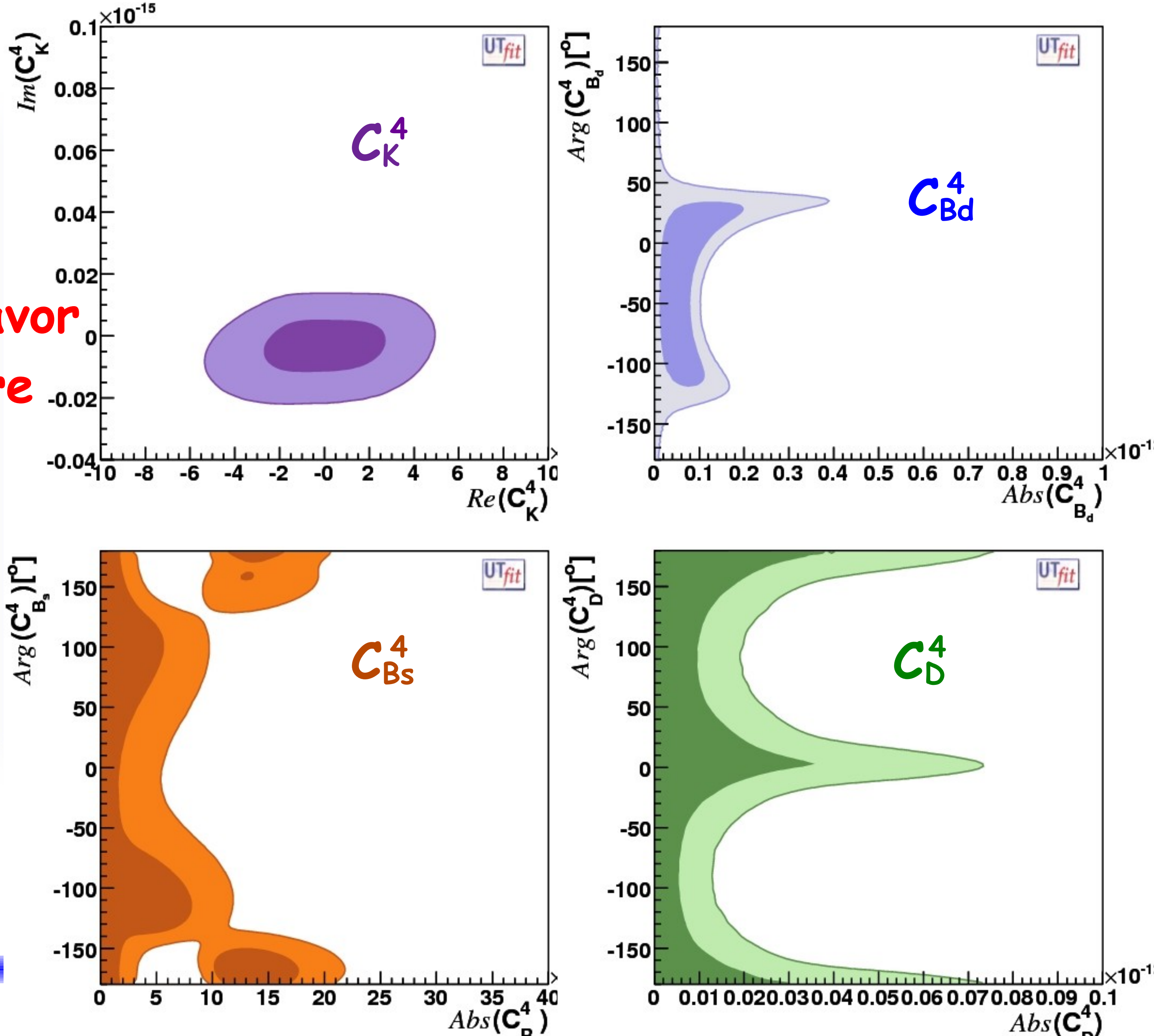
a ~ α_W (α_s) in case of loop coupling through weak (strong) interactions

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

More detailed strategy according to tanβ value

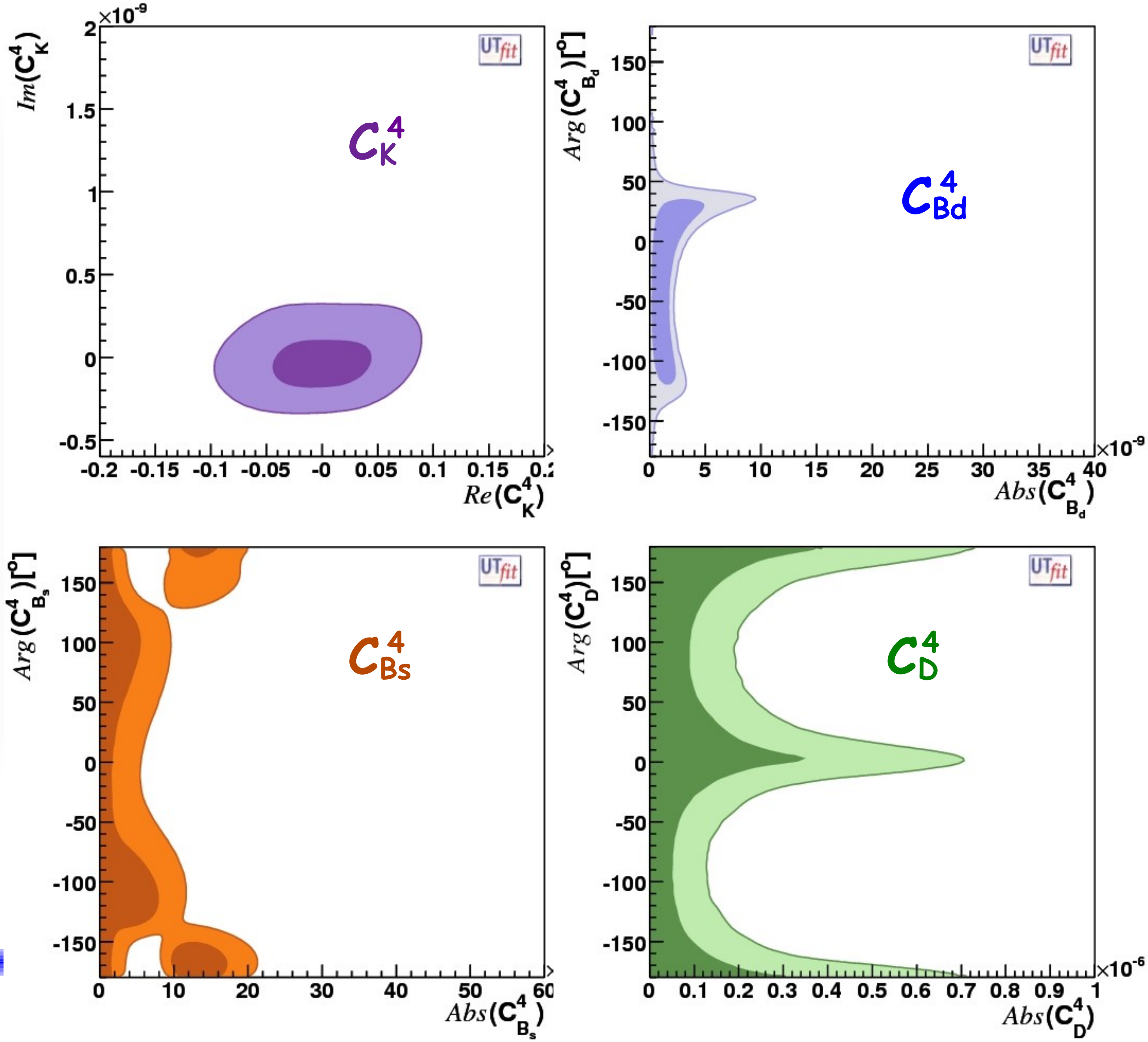
From Wilson Coeff. to NP Scale (II)

Generic Flavor Structure

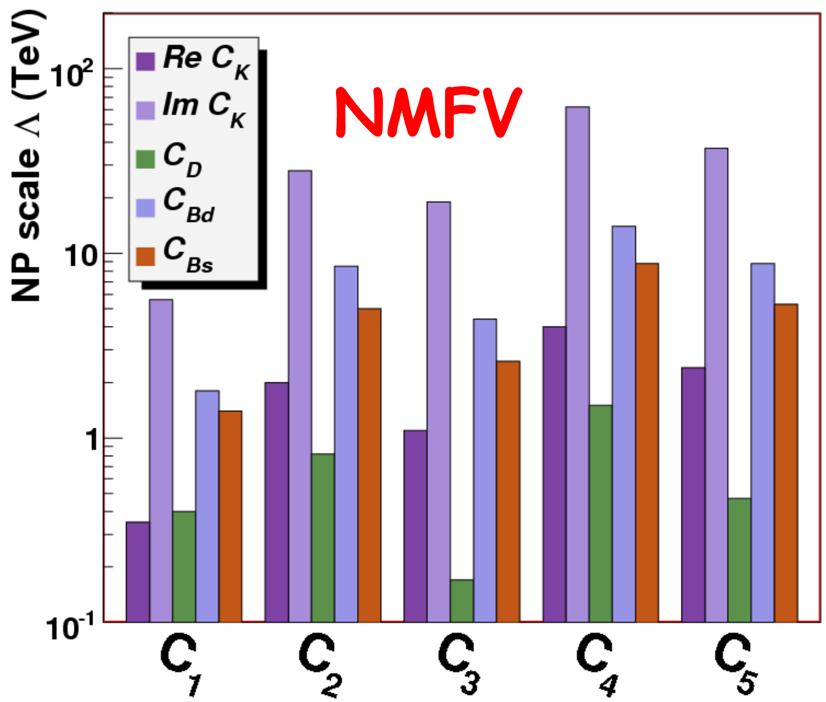


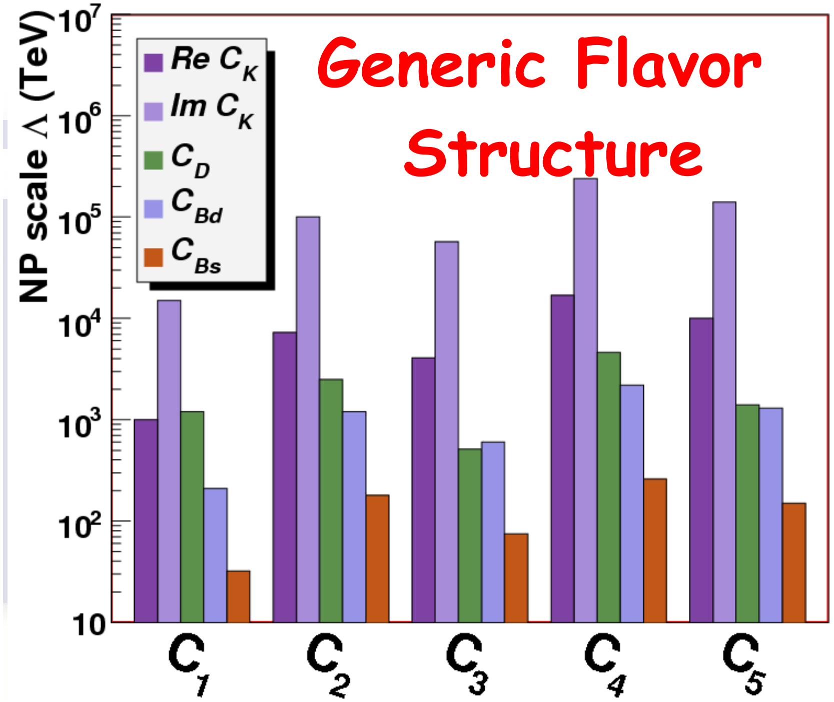
From Wilson Coeff. to NP Scale (II)

NMFV



From Wilson Coeff. to NP Scale (III)





Scale in TeV for different scenarios and different couplings

Scenario	strong/tree	α_s loop	α_W loop
NMFV	62	6.2	2
General	24000	2400	800

Cannot explain NP (if) seen at LHC

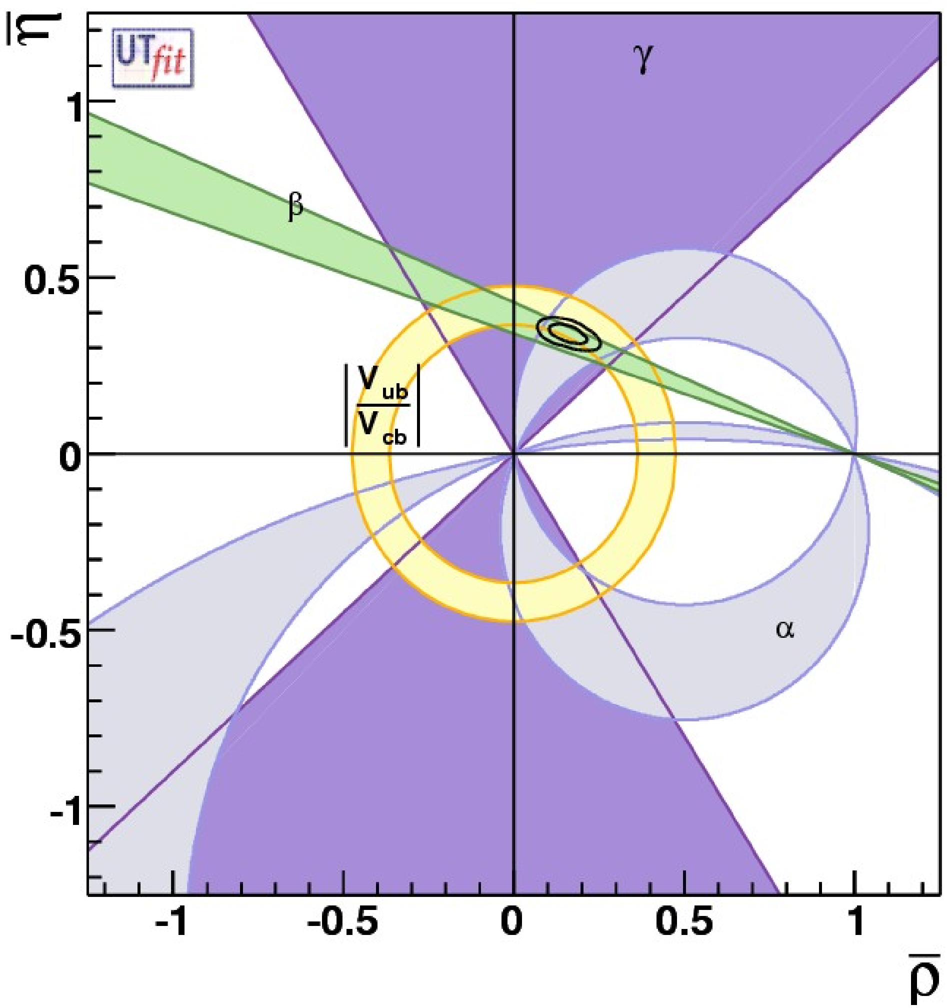
Not a first year physics (small couplings means small production rates)

Minimal Flavor Violation (I)

All tree-level and CP violating processes are constrained to their SM value.
A more precise determination of CKM matrix is possible, common to MFV and SM

$\bar{\rho}$ = 0.156 ± 0.039
[0.084, 0.235] @ 95% Prob.

$\bar{\eta}$ = 0.340 ± 0.019
[0.303, 0.376] @ 95% Prob.



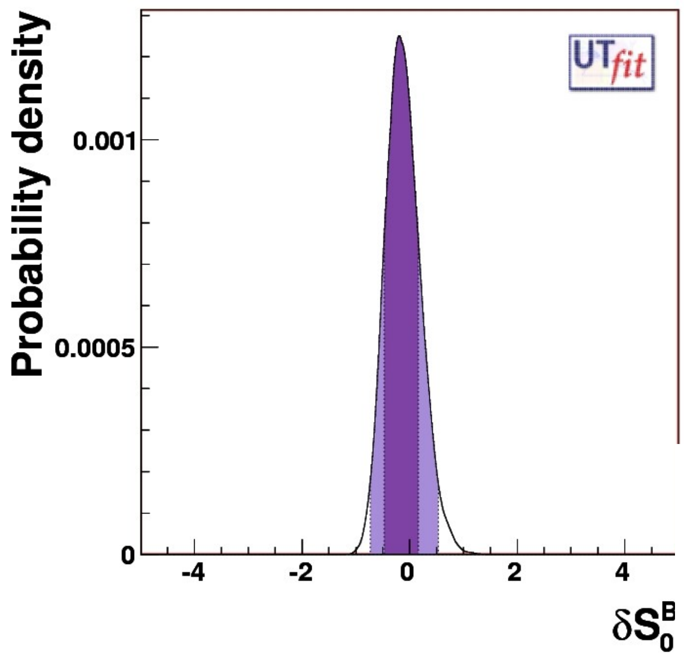
NP is a shift in the Inami-Lim functions

$$S_0(x_t) \to S_0(x_t) + \delta S_0(x_t)$$

$$\delta S_0(x_t) = 4a \left(\frac{\Lambda_0}{\Lambda}\right)^2$$

D'Ambrosio et al.
hep-ph/0207036

Minimal Flavor Violation (II)



single Higgs doublet or small tanβ:

the shift of the Inami-Lim function induced by NP is unversal.

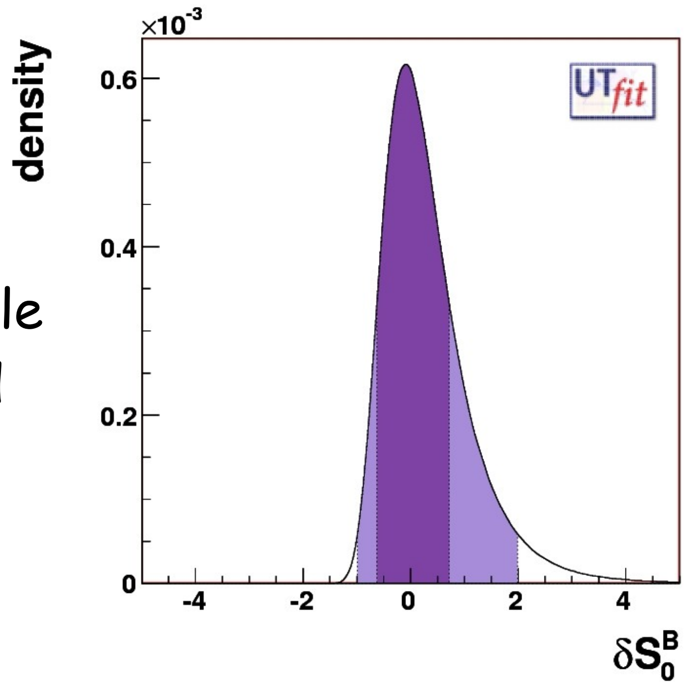
Λ>5.5 @95% prob.

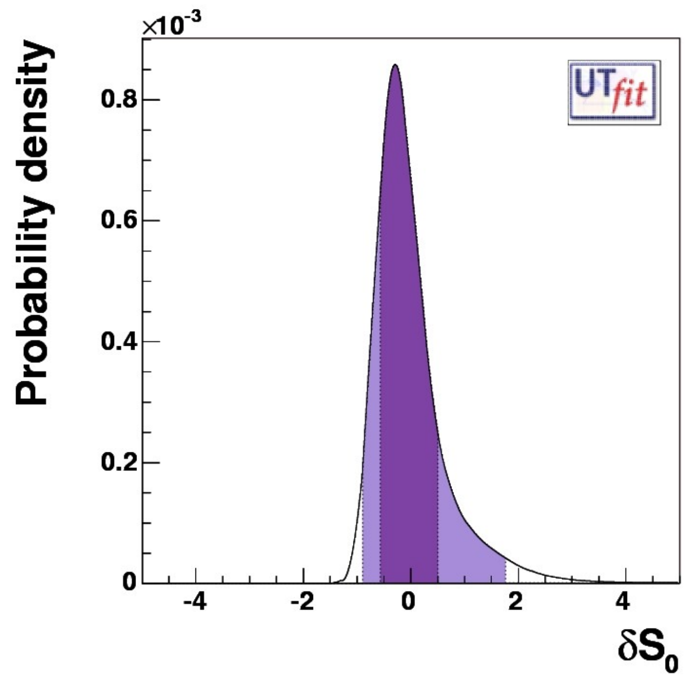
large tanβ:

Yukawa of the b plays a role

Different shifts for K and Bq mixing amplitudes

Λ>5.1 @95% prob.





Minimal Flavor Violation (III)

additional contributions to C4 (Λ) can be generated by Higgs exchange

$$C_4(\Lambda) = \frac{(a_0 + a_1)(a_0 + a_2)}{\Lambda^2} \lambda_b \lambda_q F_{\mathrm{SM}}$$

where l are the Yukawa couplings, the a's are tanb-enhanced loop factors and F_{SM} is the combination of CKM factors for the considered process. Here Λ is the scale of the non-standard Higgs.

We can then translate the bound on C into a bound on the Higgs Mass

$$\boxed{M_H > 5\sqrt{(a_0 + a_1)(a_0 + a_2)} \left(\frac{\tan\beta}{50}\right) \mathrm{TeV}}$$

Conclusions

The abundance of information from flavor physics allows to determine the CKM matrix even in presence of NP effects
The result is close to the SM one, favoring MFV scenarios for NP
If this information is used to bounds NP, NP scale is pushed beyond LHC energy range, except in some cases for which small couplings (i.e. small production rates) make the LHC discovery difficult but not impossible
For MFV, the allowed energy is accessible to LHC

Scenario	strong/tree	α_s loop	α_W loop
MFV (small $\tan\beta$)	5.5	0.5	0.2
MFV (large $\tan\beta$)	5.1	0.5	0.2
M_H in MFV at large $\tan\beta$	$5\sqrt{(a_0+a_1)(a_0+a_2)}\left(\frac{\tan\beta}{50}\right)$		

Not a first year physics (small couplings means small production rates)

These bounds represent the stringent bounds for flavor violating NP and are competitive to the EW constraints from LEP/SLD