

ETH Institute for
Particle Physics

Status of the Unitarity Triangle Analysis

Viola Sordini, on behalf of the **UTfit** collaboration

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

<http://www.utfit.org>

Outline

- CP violation in the SM: the CKM mechanism
- UTfit: method and inputs
- Inputs from Unitarity Triangle Analysis (UTA)
- Actual constraint on the CKM parameters from all measurements
- Compatibility plots – tension in the fit?
- UTfit and lattice QCD
- UTA and NP
- Conclusions

CP violation and CKM matrix

weak interaction eigenstates mass eigenstates

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \boxed{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

V_{CKM} Unitary matrix

**Cabibbo
Kobayashi
Maskawa**

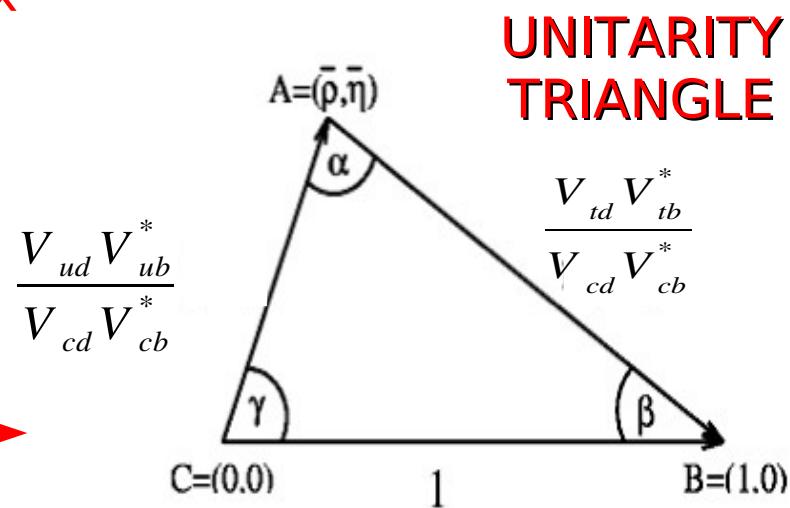
UNITARITY CONDITION:

$$V_{CKM} V_{CKM}^+ = V_{CKM}^+ V_{CKM} = 1$$

six independent relations,
within them we choose:

$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0 \quad \rightarrow$$

B physics



In a complex plane $(\bar{\rho}, \bar{\eta})$

Method and Inputs

Bayes theorem

$$f(\bar{\rho}, \bar{\eta}, x_1, x_2, \dots, x_N | c_1, c_2, \dots, c_M) \propto \\ \propto \prod_{j=1}^M f_i(c_j | \bar{\rho}, \bar{\eta}, x_1, \dots, x_N) \prod_{i=1}^N f_i(x_i) f_0(\bar{\rho}, \bar{\eta})$$

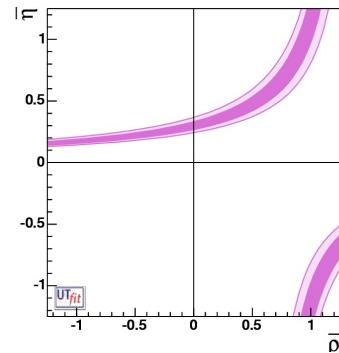
with

$$x_i = B_K, f_{B_d}, \dots$$

$$c_i = \epsilon_K, \Delta M_{d,s}, A_{CP}(J/\Psi K_S) \dots$$

M.Ciuchini et al. JHEP 0107 (2001) 013.
hep-ph/0012308

Constraints $c_i \sim f_i(c_i | \rho, \eta, \dots)$

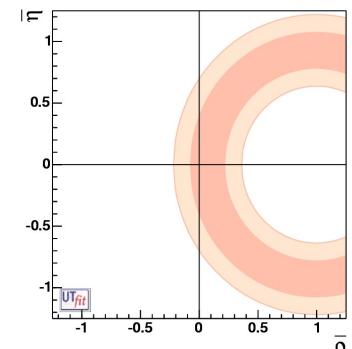
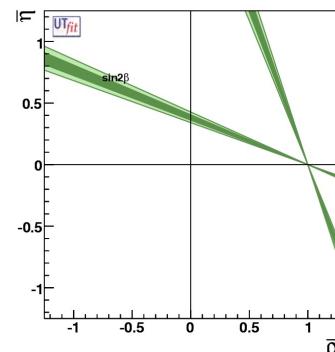
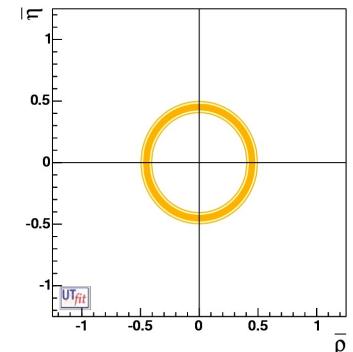


$(b \rightarrow u)/(b \rightarrow c)$	$\bar{\rho}^2 + \bar{\eta}^2$	$(\bar{\Lambda}), \lambda_1, F(1)$
---------------------------------------	-------------------------------	------------------------------------

ϵ_K	$\bar{\eta}[(1 - \bar{\rho}) + P]$	B_K
--------------	------------------------------------	-------

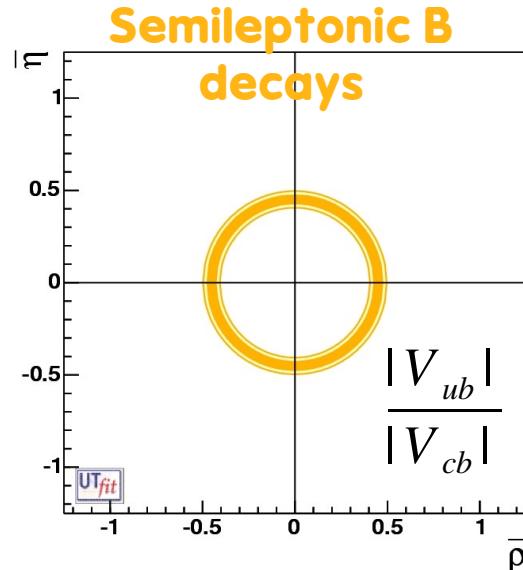
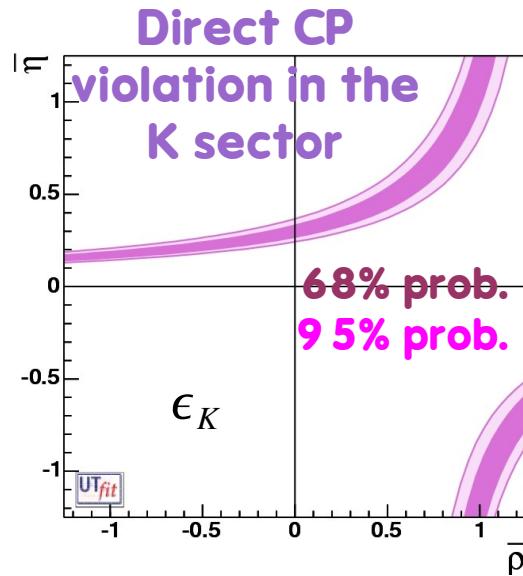
$\Delta m_d, \Delta m_d / \Delta m_s$	$(1 - \bar{\rho})^2 + \bar{\eta}^2$	$f_B^2 B_B, \xi$
---------------------------------------	-------------------------------------	------------------

$A_{(CP)}(J/\Psi K_S)$	$\sin 2\beta$	
------------------------	---------------	--

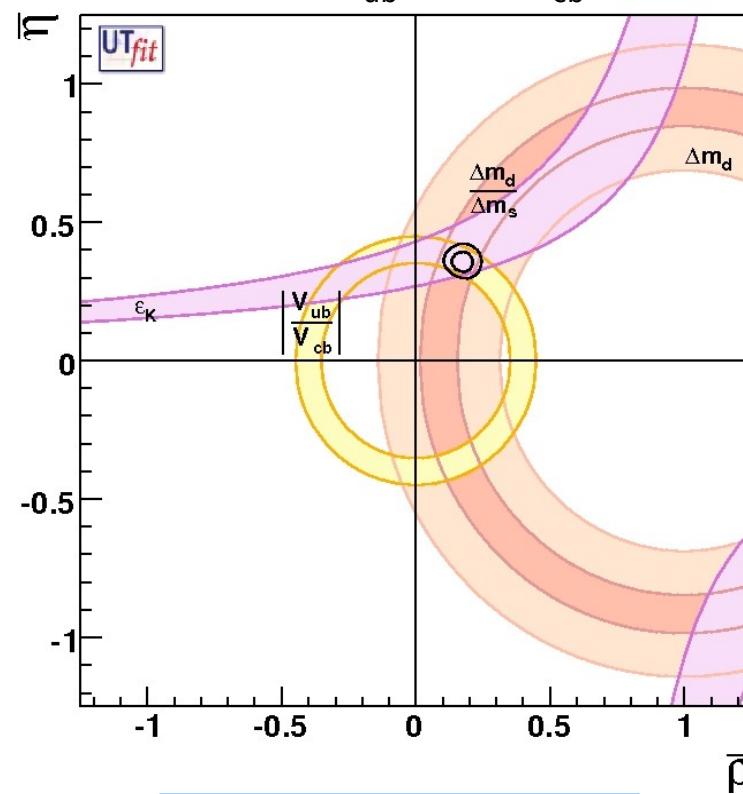


M.Bona et al. (UTfit collaboration)
JHEP 0507 (2005) 028. hep-ph/0501199

Sides + ϵ_K : inputs and results

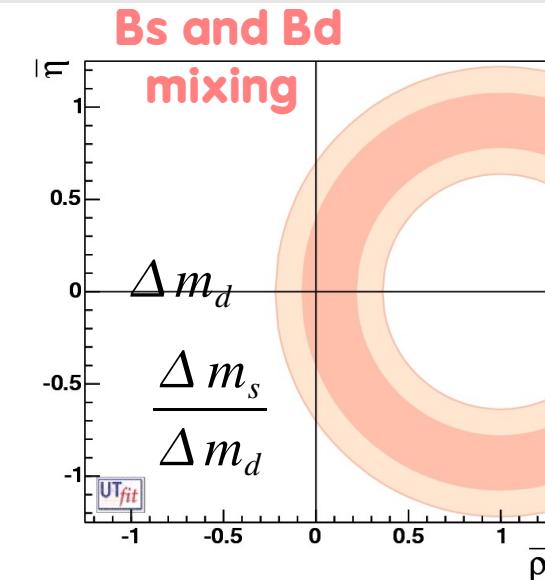


LEP-time analysis (with big recent contribution from Tevatron for Δm_s and B-factories for V_{ub} and V_{cb})



$$\bar{\rho} = 0.177 \pm 0.028$$

$$\bar{\eta} = 0.358 \pm 0.026$$

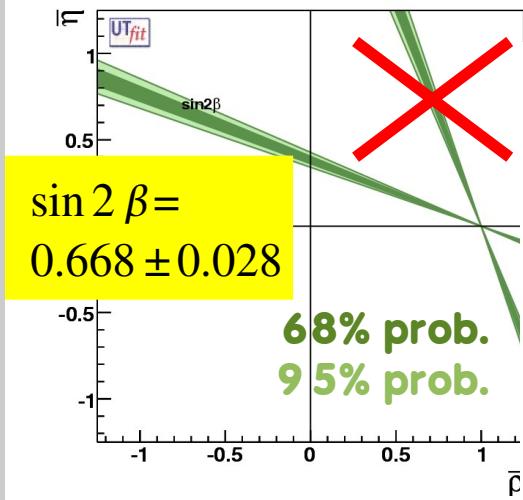


Contours at 68% and 95% probability are shown

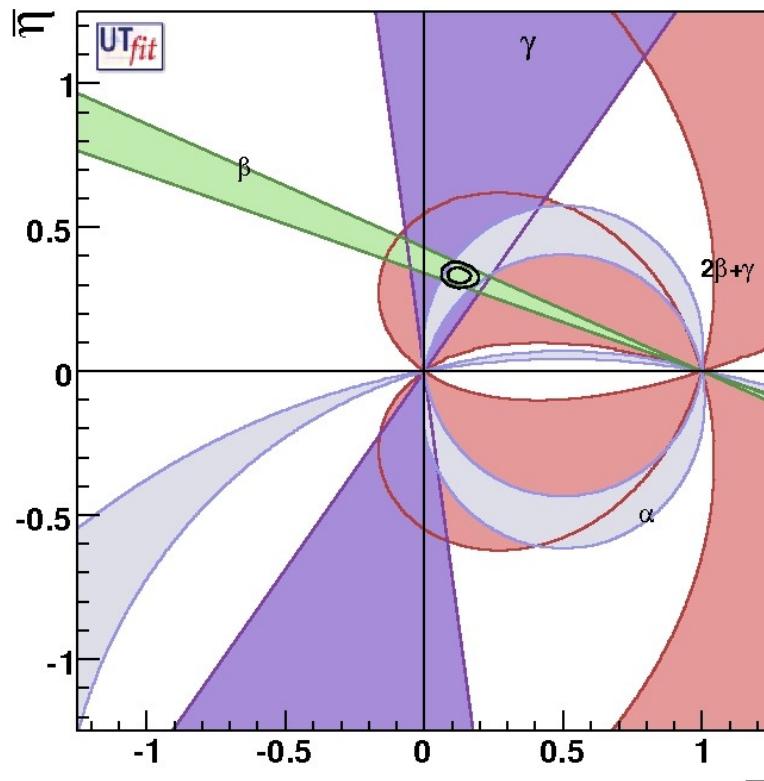
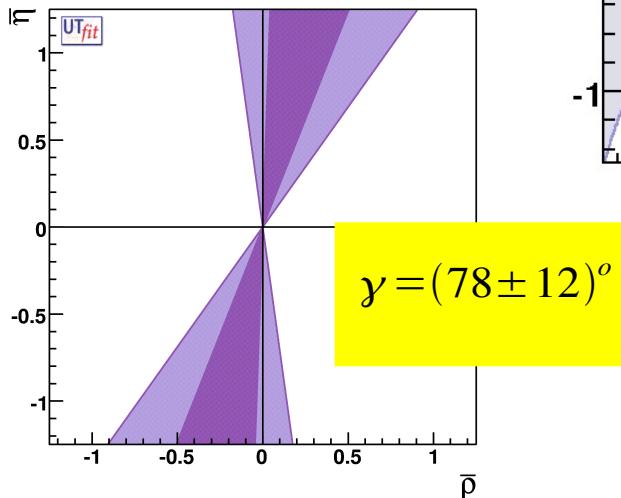
Dependence on non-perturbative hadronic parameters

Angles: inputs and results

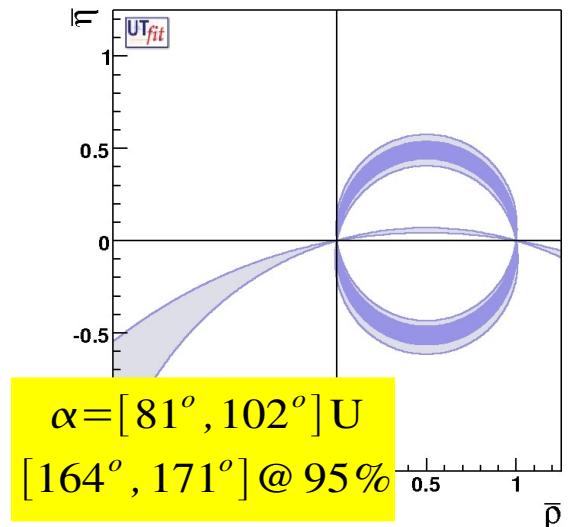
B_d mixing



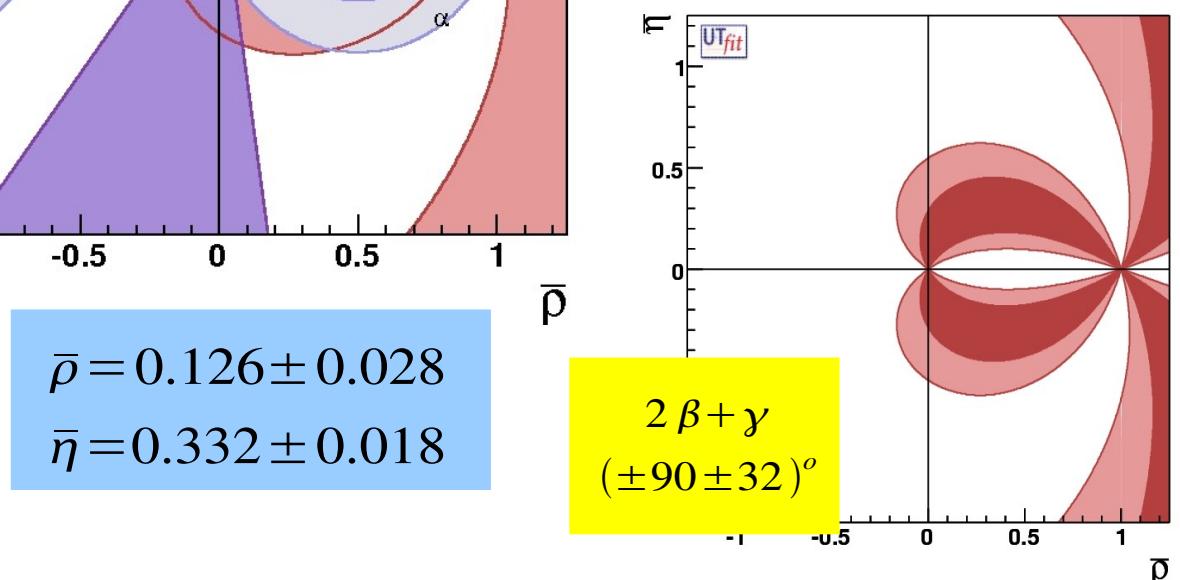
$B \rightarrow D(*^0) K(*)$



$B \rightarrow \pi\pi, \rho\rho, \rho\pi$

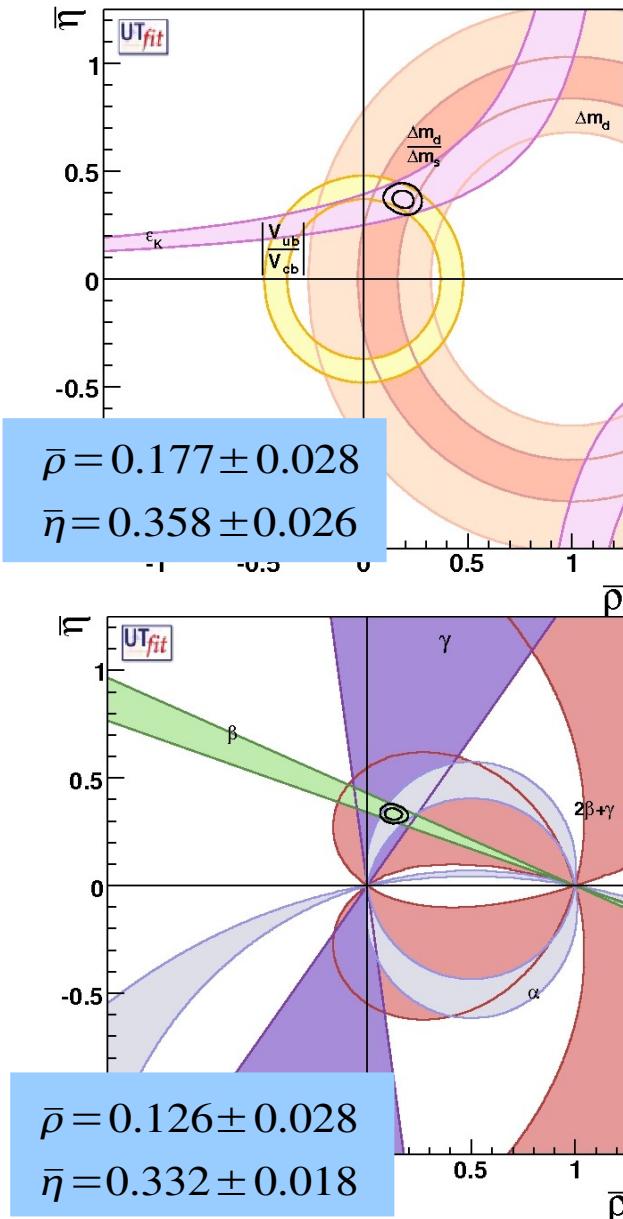


$B^0 \rightarrow D(*) \pi, D \rho, D K \pi$



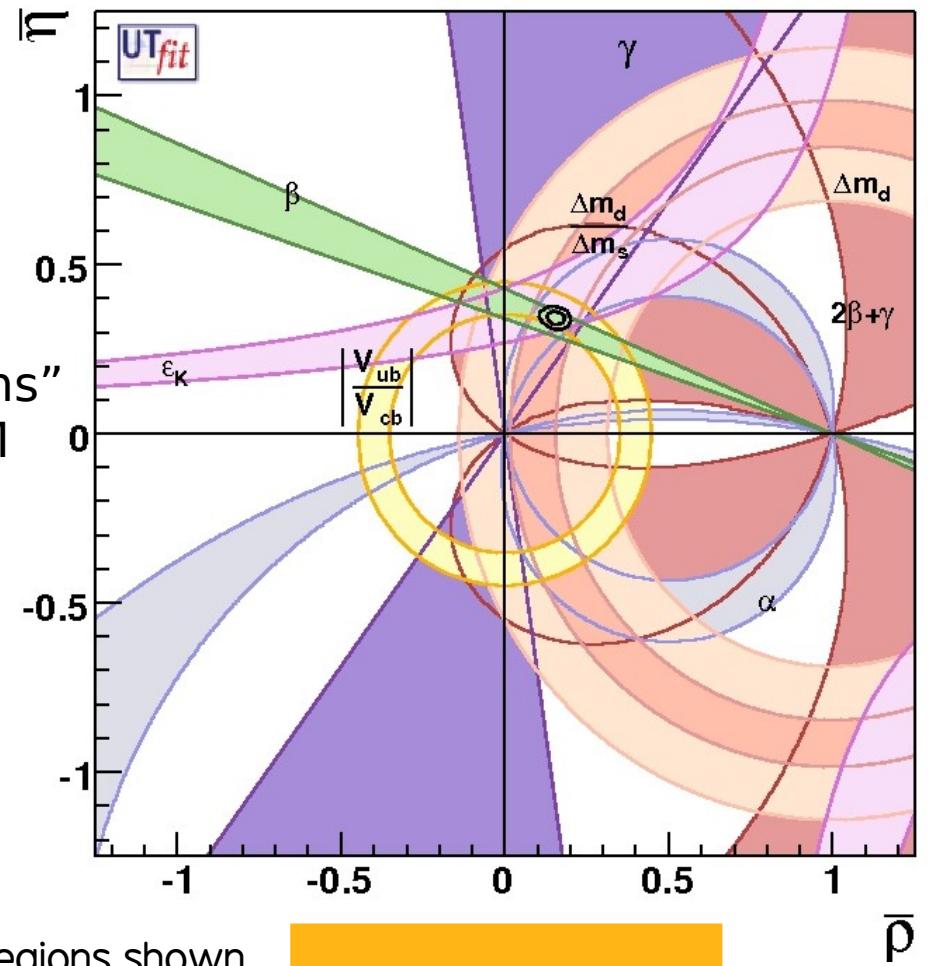
$$\begin{aligned}\bar{\rho} &= 0.126 \pm 0.028 \\ \bar{\eta} &= 0.332 \pm 0.018\end{aligned}$$

Results



<http://www.utfit.org>

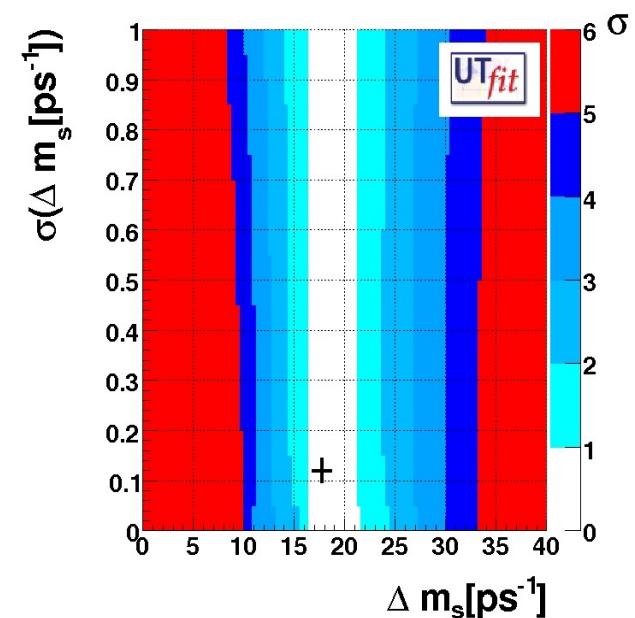
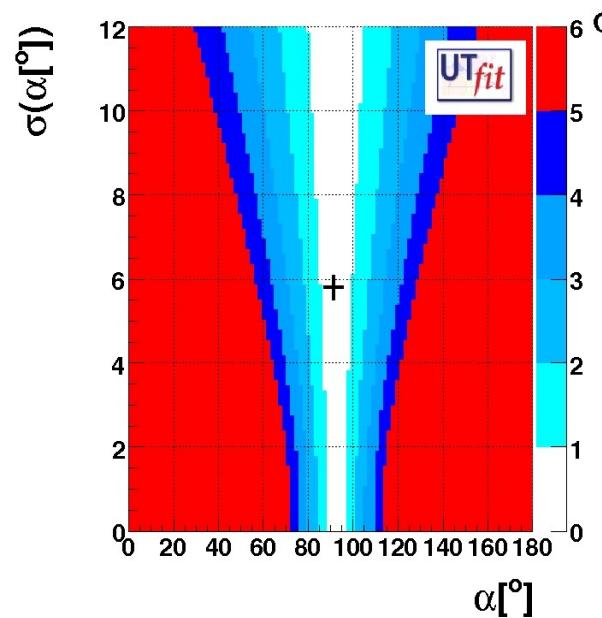
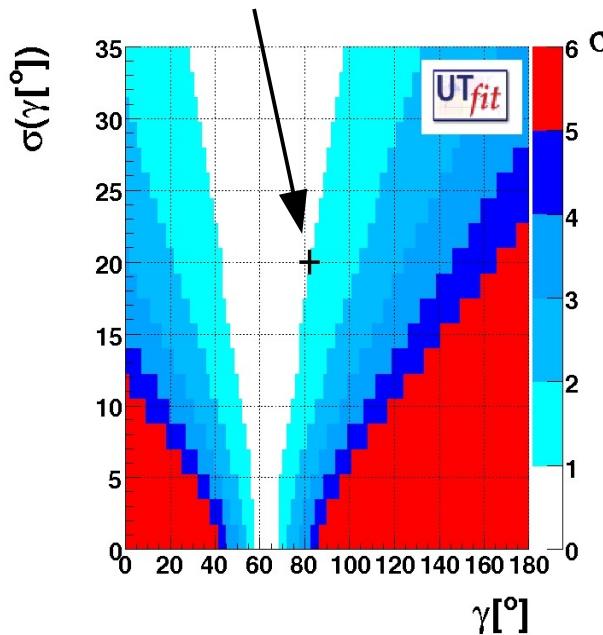
NP should appear as
“corrections”
to the CKM pictures



Compatibility plots

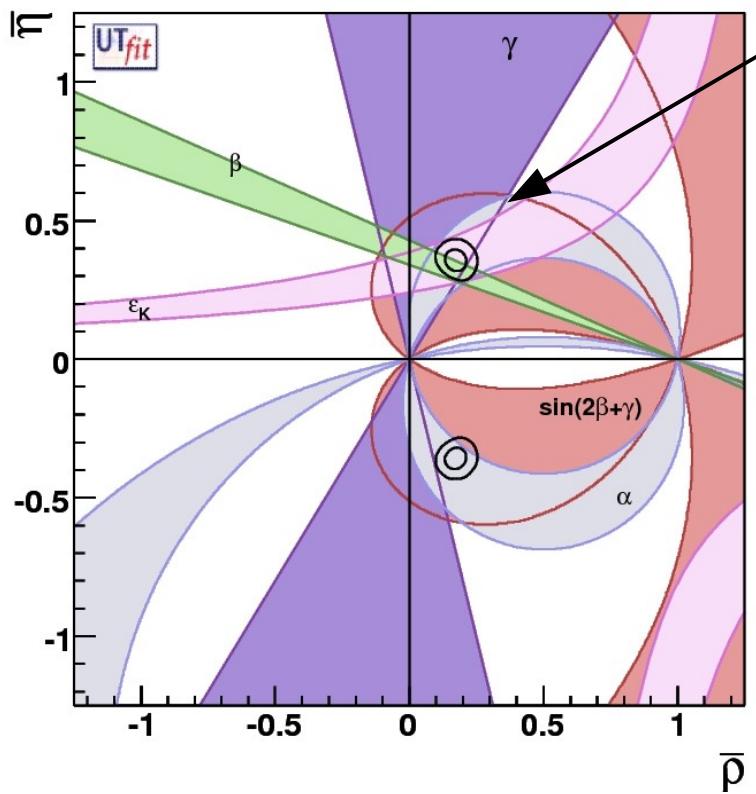
A way to “measure” the agreement of a single measurement with the indirect determination from the fit using all the other inputs: test for the SM description of the flavor physics

The cross has the coordinates $(x,y)=(\text{central value}, \text{error})$
of the direct measurement

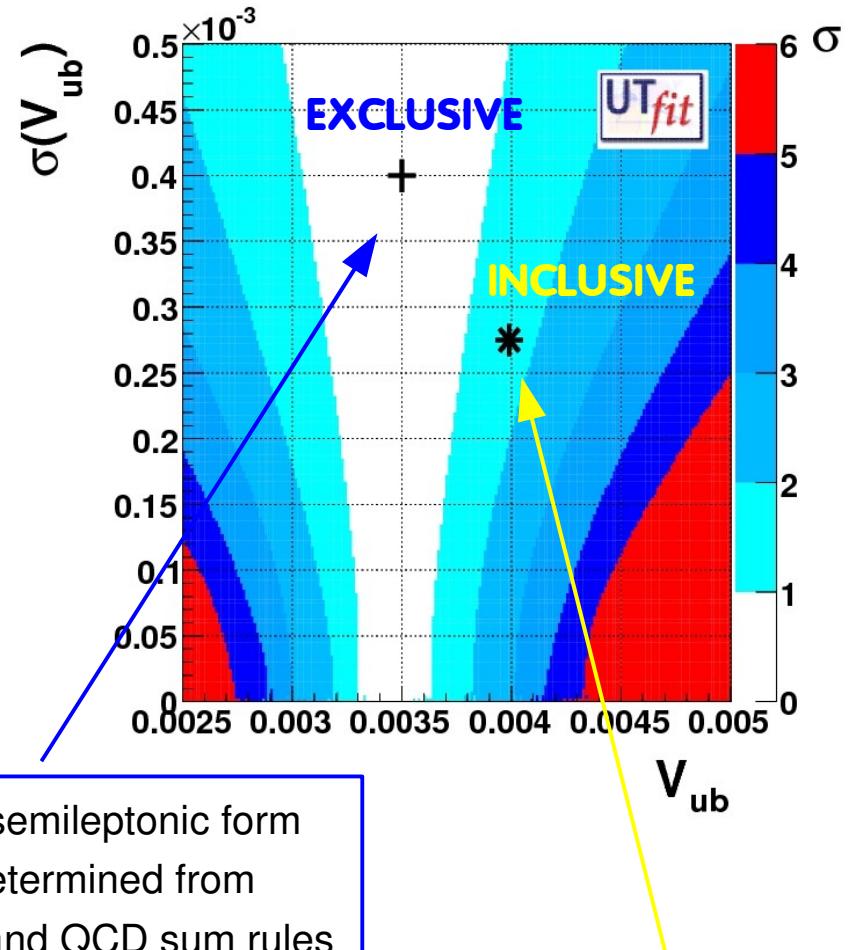


Color code: agreement between the predicted values
and the measurements at better than $1, 2\dots n \sigma$

Tension in the fit?



Contours (68% and 95%) for the vertex position determined by $\Delta m_s/\Delta m_d$, $|V_{ub}/V_{cb}|$



Relying on semileptonic form factors determined from Lattice QCD and QCD sum rules

$$V_{ub}^{\text{INDIRECT}} = (3.48 \pm 0.16) 10^{-3}$$

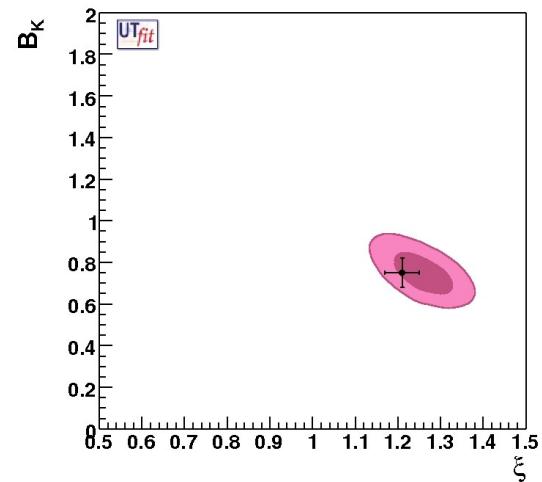
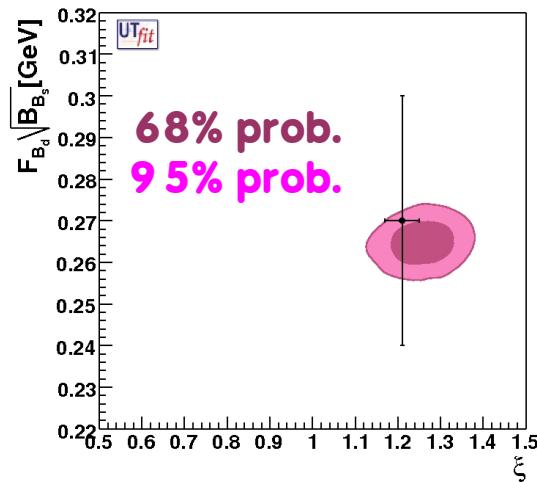
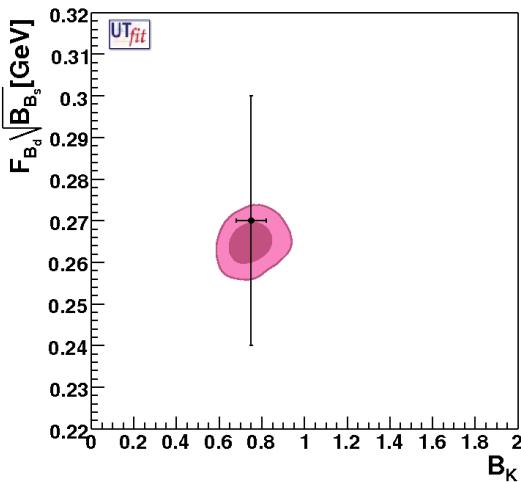
$$V_{ub}^{\text{Exclusive}} = (3.50 \pm 0.40) 10^{-3}$$

$$V_{ub}^{\text{Inclusive}} = (3.99 \pm 0.15 \pm 0.40 [\text{flat}]) 10^{-3}$$

Relying on some HQET parameters extracted from experimental fits with some model dependence

UTfit vs lattice QCD

Fit overconstrained: UT analysis without relying on theoretical calculations of hadronic matrix elements. Using angles measurements, $|V_{ub}/V_{cb}|$ to determine CKM parameters and Δm_d , Δm_s , and ϵ_K to determine the LQCD quantities (assuming the validity of the SM).



Main goal: identify where lattice QCD calculation improvements are necessary

Parameter	UTangle	UTangle + V_{ub}/V_{cb}	lattice QCD results
B_K	0.78 ± 0.07	0.75 ± 0.07	0.75 ± 0.07
$f_{B_s}\sqrt{B_{B_s}}$ (MeV)	265.6 ± 3.6	264.7 ± 3.6	270 ± 30
ξ	1.27 ± 0.05	1.26 ± 0.05	1.21 ± 0.04
f_{B_d} (MeV)	191 ± 13	191 ± 13	200 ± 20

(V. Lubicz,
C. Tarantino,
arXiv:
0807.4605
[hep-lat])

UTA beyond the SM

- start from a NP-free CKM determination
- parametrize generic NP in all sectors
- fit simultaneously for CKM and NP parameters

General parametrization for B_q - \bar{B}_q mixing ($q=d,s$)

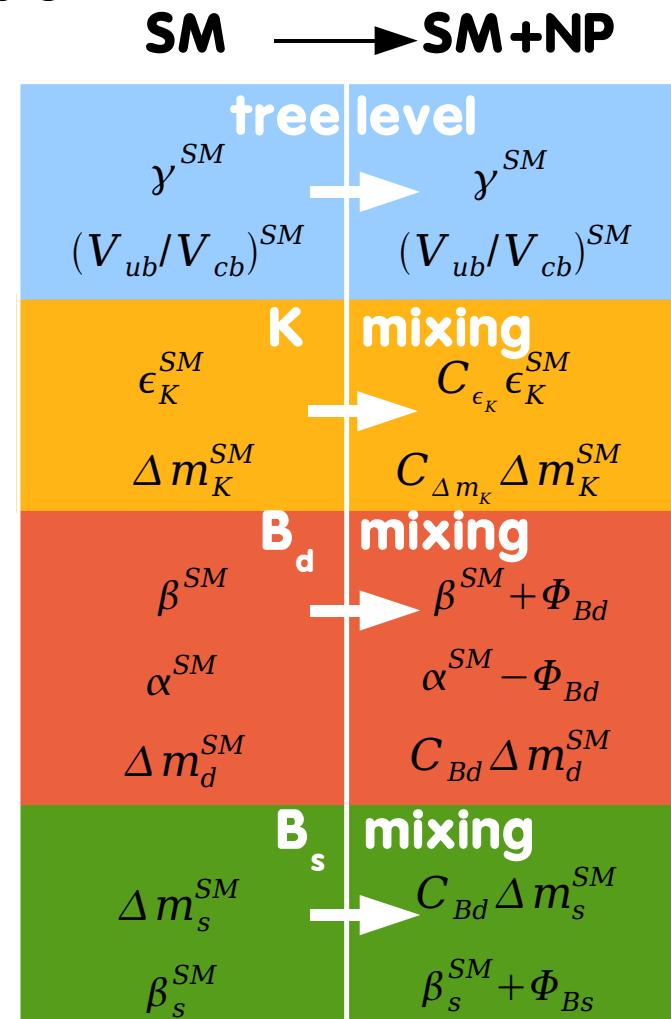
$$C_{Bq} e^{2i\phi_{Bq}} = \frac{\langle B_q | H_{SM+NP} | \bar{B}_q \rangle}{\langle B_q | H_{SM} | \bar{B}_q \rangle} = \\ = 1 + \frac{A_q^{NP} e^{2i\phi_q^{NP}}}{A_q^{SM} e^{2i\phi_q^{SM}}}$$

where:

$$\phi_d^{SM} = \beta \quad \phi_s^{SM} = -\beta_s$$

$$C_{SM} = 1$$

$$\phi_{SM} = 0$$



Additional constraints for NP analysis

$$\Delta m_s = |A_{full}^s| = C_{B_s} \Delta m_s^{SM} \quad 2\phi_s = \arg(A_{full}^s) = 2(\beta_s - \phi_{B_s})$$

- semileptonic asymmetry in B_s , A_{SL}^s ([D0 Collaboration] Phys. Rev. Lett. 98:151801, 2007)

$$A_{SL}^s = \frac{\Gamma(\bar{B}_s \rightarrow l^+ X) - \Gamma(\bar{B}_s \rightarrow l^- X)}{\Gamma(\bar{B}_s \rightarrow l^+ X) + \Gamma(\bar{B}_s \rightarrow l^- X)} = \text{Im}\left(\frac{\Gamma_{12}^s}{A_{full}^s}\right)$$

- dimuon charge asymmetry, $A_{SL}^{\mu\mu}$ ([D0 collaboration] Phys. Rev. D74:092001, 2006 – [CDF collaboration] note 9015)

$$A_{SL}^{\mu\mu} = \frac{f_d \chi_{d0} A_{SL}^d + f_s \chi_{s0} A_{SL}^s}{f_d \chi_{d0} + f_s \chi_{s0}}$$

- B_s lifetime measurement from flavor specific final states, $\tau_{B_s}^{FS}$ (ALEPH, CDF, DELPHI, D0, OPAL, see ref [19] in arXiv:0803.0659)

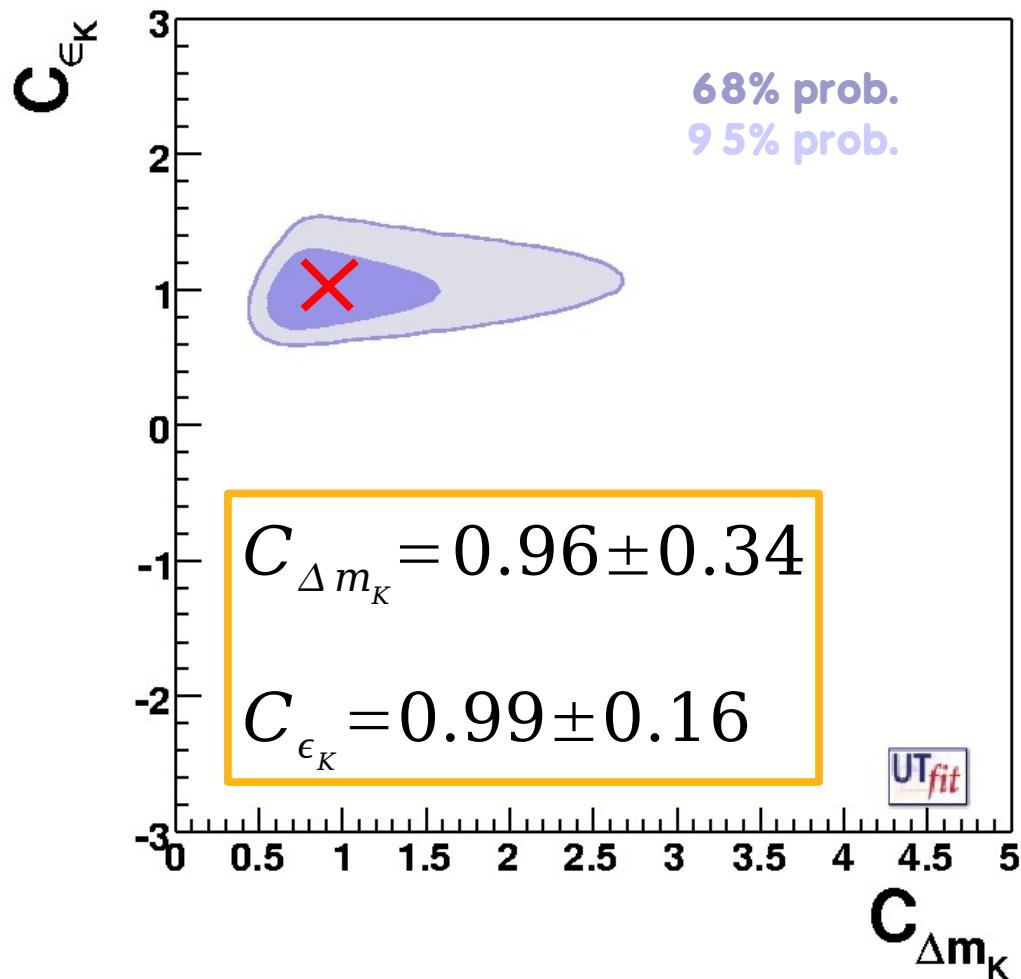
$$\tau_{B_s}^{FS} = \frac{1}{\Gamma_s} \frac{1 - \left(\frac{\Delta \Gamma_s}{2 \Gamma_s}\right)^2}{1 + \left(\frac{\Delta \Gamma_s}{2 \Gamma_s}\right)^2}$$

- two-dimensional likelihood scan for $\Delta \Gamma_s$ and ϕ_s from the flavor-tagged analysis $B_s \rightarrow J/\psi \phi$ ([D0 Collaboration] arXiv:0802.2255)
- two-dimensional likelihood ratio for $\Delta \Gamma_s$ and ϕ_s from the time dependent tagged angular analysis $B_s \rightarrow J/\psi \phi$ ([CDF collaboration] arXiv:0712.2397)

see A. Chandra talk on Monday

New physics in K sector

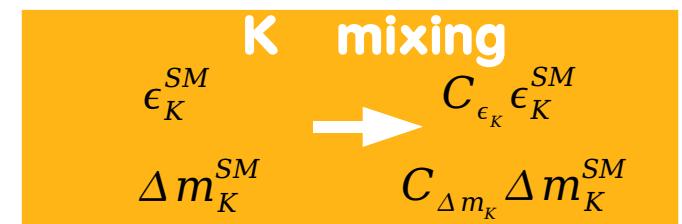
NP contributions to the K mixing



$$C_{\epsilon_K} = \frac{\text{Im} \langle K^0 | H_{SM+NP} | \bar{K}^0 \rangle}{\text{Im} \langle K^0 | H_{SM} | \bar{K}^0 \rangle}$$

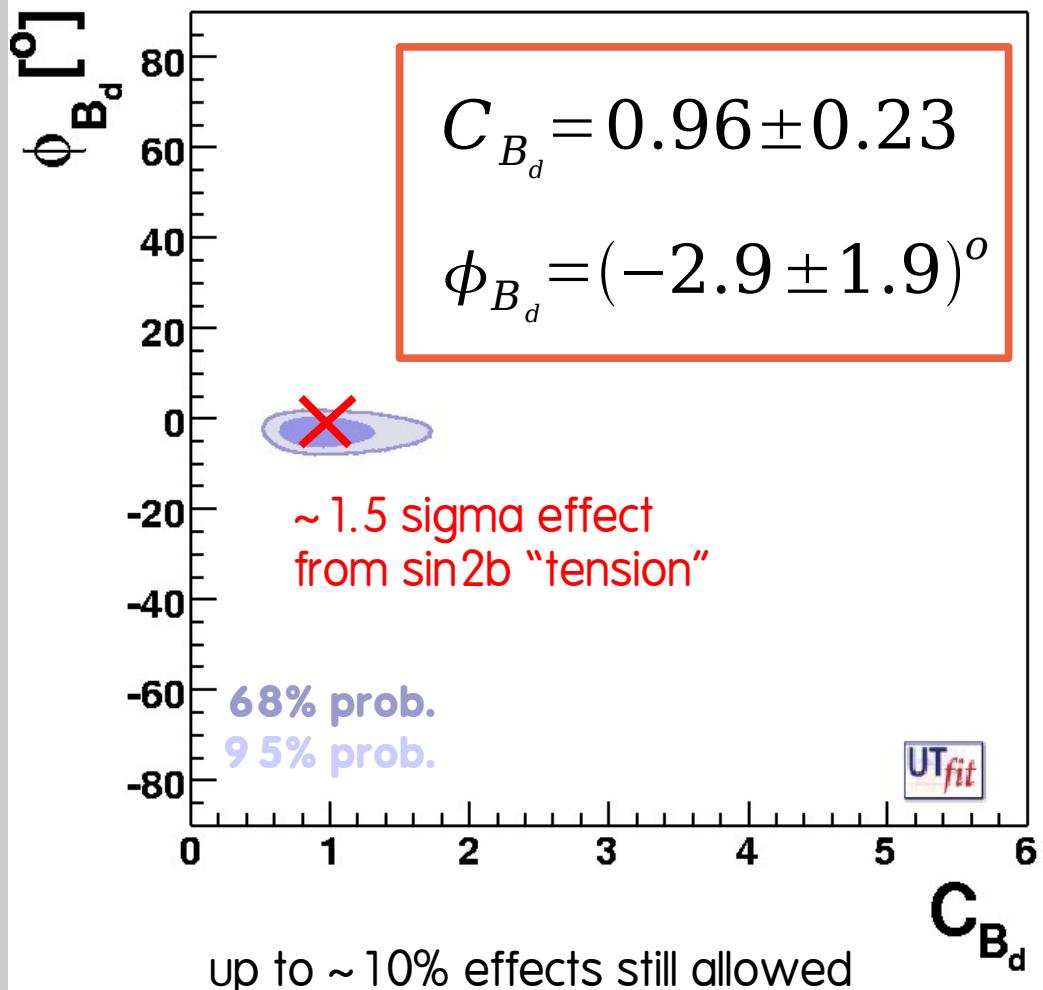
$$C_{\Delta m_K} = \frac{\text{Re} \langle K^0 | H_{SM+NP} | \bar{K}^0 \rangle}{\text{Re} \langle K^0 | H_{SM} | \bar{K}^0 \rangle}$$

SM \longrightarrow **SM+NP**



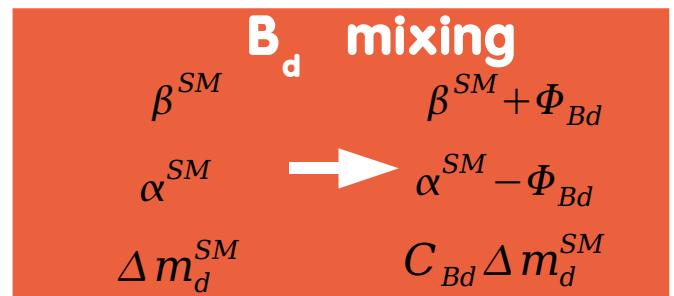
New physics in B_d sector

NP contributions to the B_d mixing



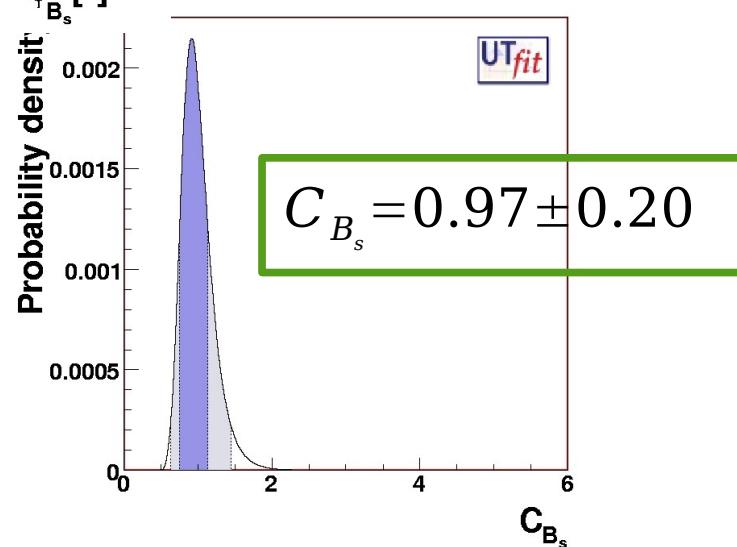
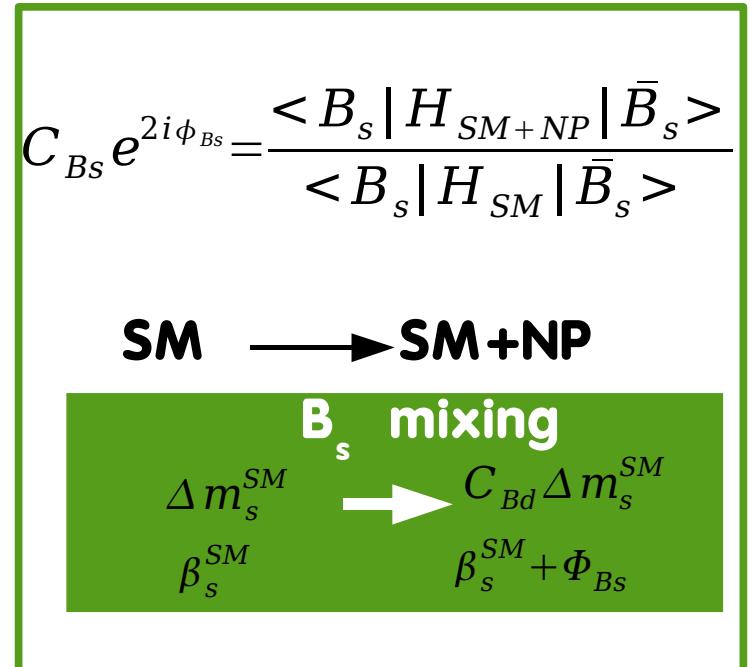
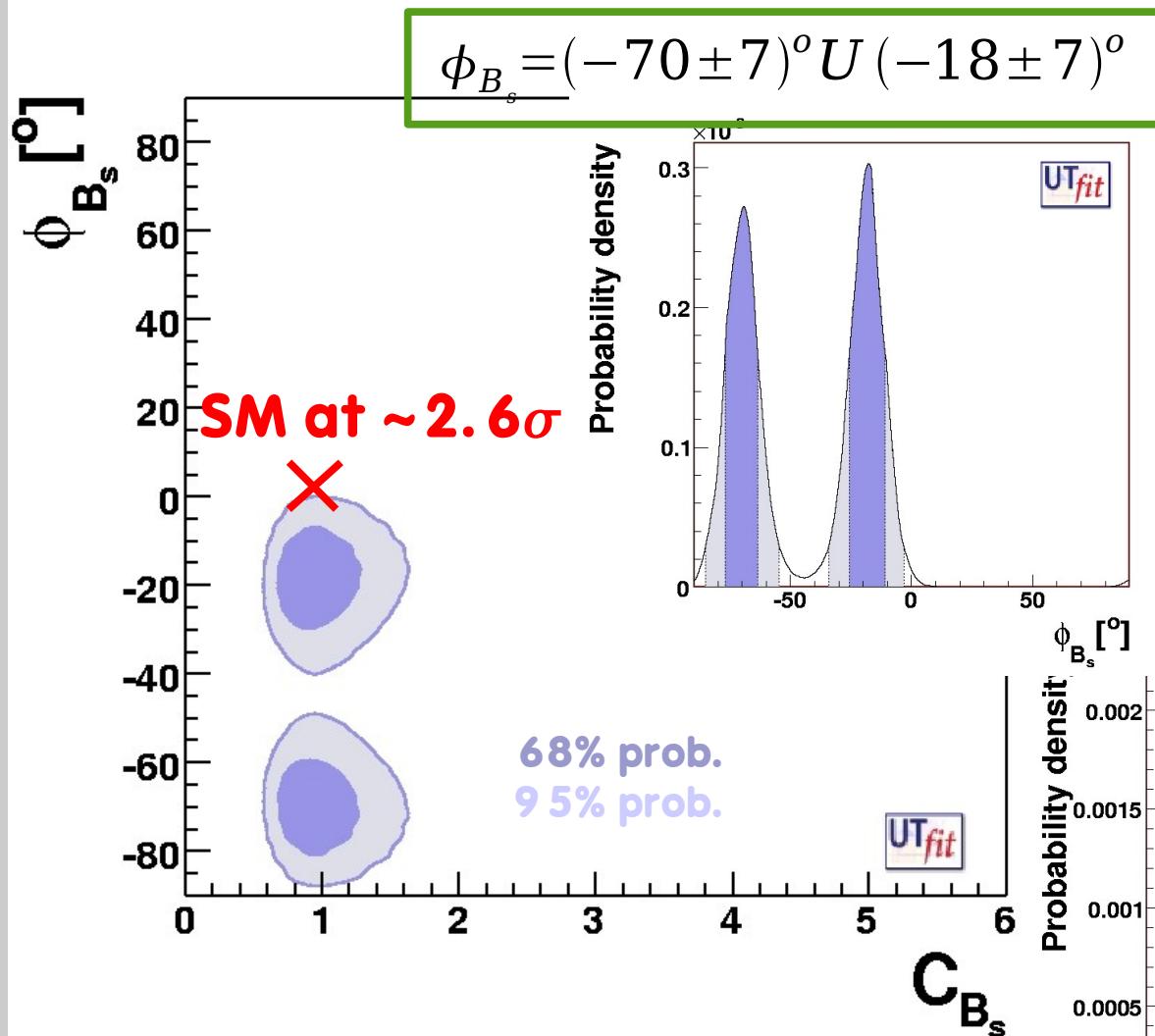
$$C_{B_d} e^{2i\phi_{B_d}} = \frac{\langle B_d | H_{SM+NP} | \bar{B}_d \rangle}{\langle B_d | H_{SM} | \bar{B}_d \rangle}$$

SM \longrightarrow **SM+NP**



New physics in B_s sector

NP contributions to the B_s mixing



Conclusions

- Combination of all the available information
<http://www.utfit.org>
- SM description of CP violation through the CKM mechanism is successful: all experimental measurements in agreement, physics beyond the SM should appear as a correction
- Small tension in the fit, due to the V_{ub} measurement
- Extraction of hadronic parameters
- Indication for NP with new sources of flavor violation. Clear pattern arises:
 - $1 \leftrightarrow 2$: strongly suppressed
 - $1 \leftrightarrow 3$: $\leq O(10\%)$
 - $2 \leftrightarrow 3$: $O(1)$

References

<http://www.utfit.org/>

Ciuchini et al. "2000 CKM triangle analysis: A Critical review with updated experimental inputs and theoretical parameters." JHEP 0107:013,2001 (hep-ph/0012308)

M. Bona et al. [UTfit Collaboration]

"The Unitarity Triangle Fit in the Standard Model and Hadronic Parameters from Lattice QCD:

A Reappraisal after the Measurements of Δm_s and $\text{BR}(B \rightarrow \tau\nu)$ "

JHEP 0610:081,2006 (hep-ph/0606167)

M. Bona et al. [UTfit Collaboration]

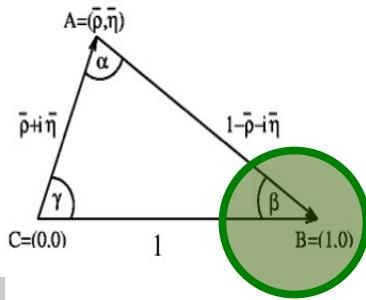
"The 2004 UTfit Collaboration Report on the Status of the Unitarity Triangle in the Standard Model",

JHEP 0507 (2005) 028 (hep-ph/0501199)

M. Bona et al. [UTfit Collaboration]

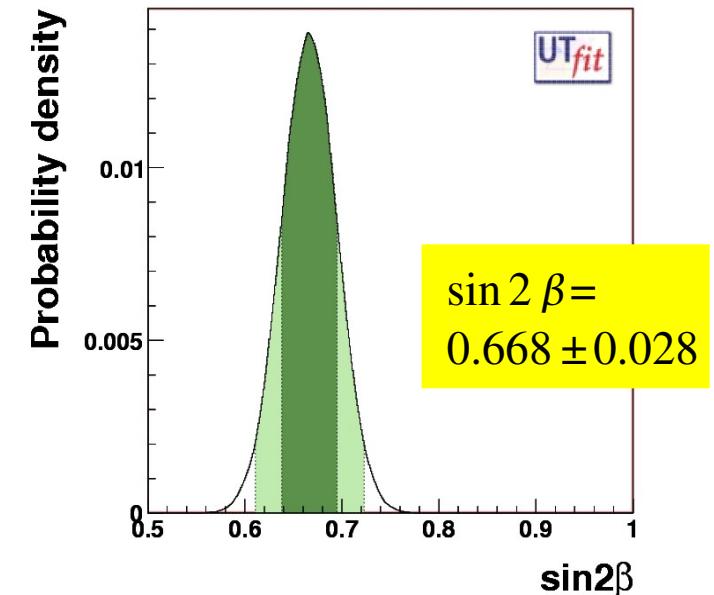
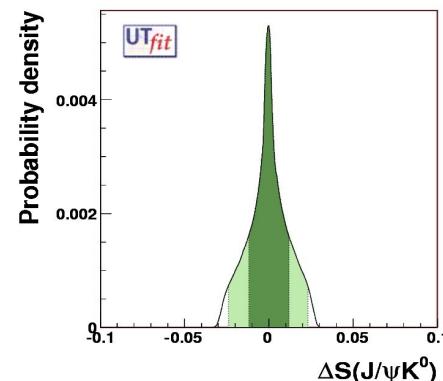
"Model-independent constraints on Delta F=2 operators and the scale of New Physics" 0707.0636 (hep-ph)]

Backup

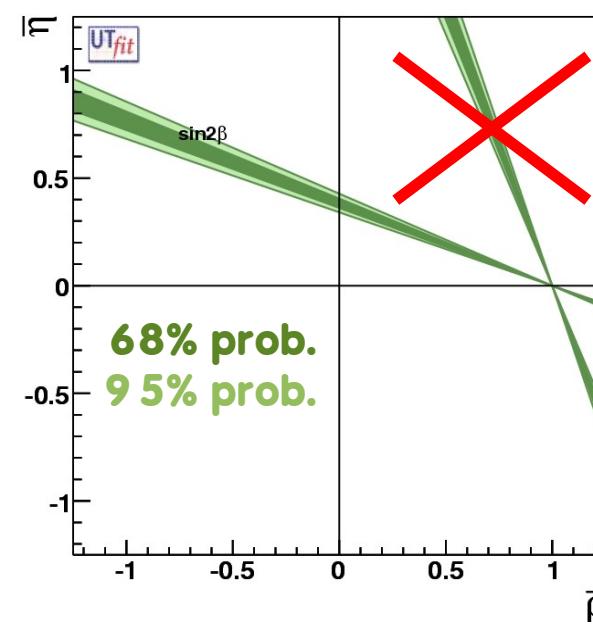
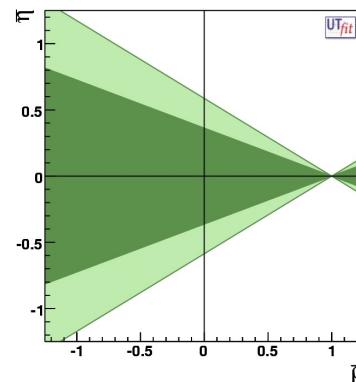


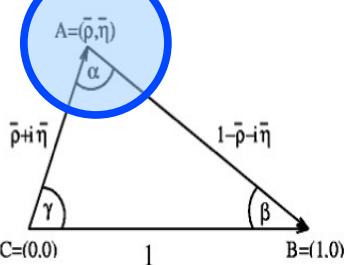
Angles, inputs

$\sin 2\beta$: from the time dependent asymmetry measurement in $B^0 \rightarrow J/\Psi K_S$ only, theoretical error taken into account (Ciuchini et al. PRL95 : 221804, 2005).



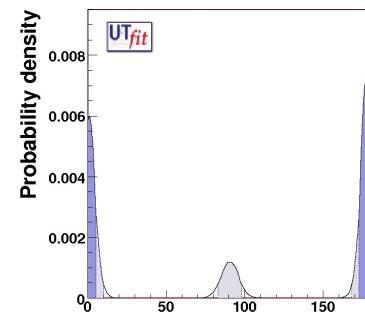
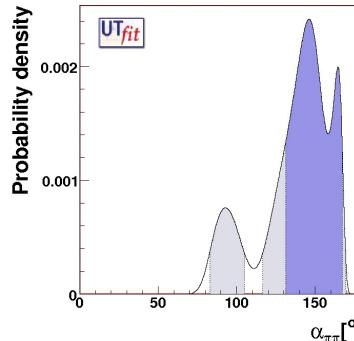
Ambiguity removed by measurements from angular analysis of time dependent studies in $B^0 \rightarrow J/\Psi K_S^*$ and Dalitz analysis of $B^0 \rightarrow D^0 \pi^0$





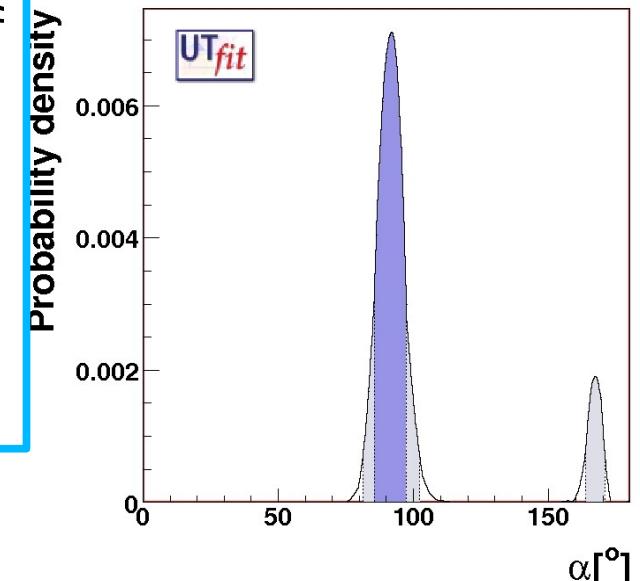
Angles, inputs

TD A_{CP} and BRs for $B \rightarrow \pi\pi$ and $B \rightarrow \rho\rho$ + isospin analysis



M.Bona et al. Hep-ph/0701204, to appear in PRD

overall constraint:



$B^0 \rightarrow (\rho\pi)^0$ analysis on the Dalitz plot.

The penguin contributions delete in:

$$A = A(B^0 \rightarrow \rho^+ \pi^-) + A(B^0 \rightarrow \rho^- \pi^+) + 2A(B^0 \rightarrow \rho^0 \pi^0) = \\ = (T_{+-} + T_{-+} + 2T_{00}) e^{-i\alpha}$$

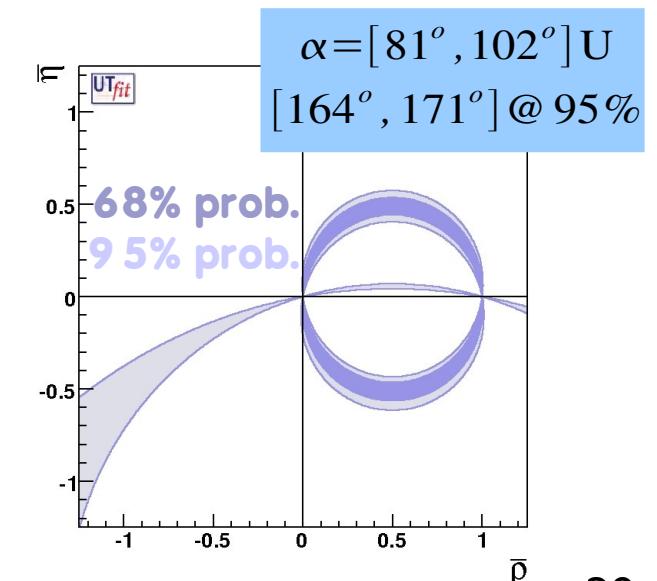
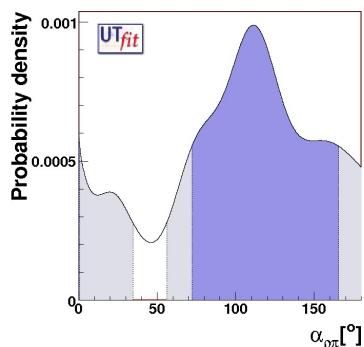
and similarly A_{bar} , for CP conjugated.

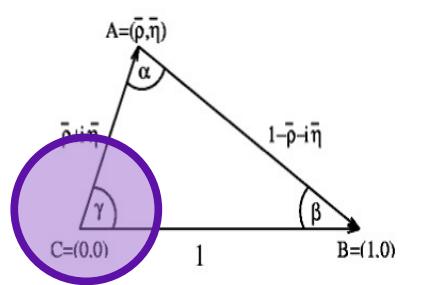
We extract α directly from data measuring

$$R = A_{bar}/A = e^{2i\alpha}$$

Penguin contributions cancel out in the sum: no need to fit for them.

As for gamma from B_s (Ciuchini et al.
Phys.Lett.B645:201–203, 2007)





Angles, inputs

$$\gamma = \arg \left\{ \frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \right\}$$

$B \rightarrow D^{(*)0} (\bar{D}^{(*)0}) K^{(*)}$ decays can proceed both through V_{cb} and V_{ub} amplitudes

$D^0 (\bar{D}^0) \rightarrow K_S \pi^0, K^+ K^-, \pi^+ \pi^-$

GLW

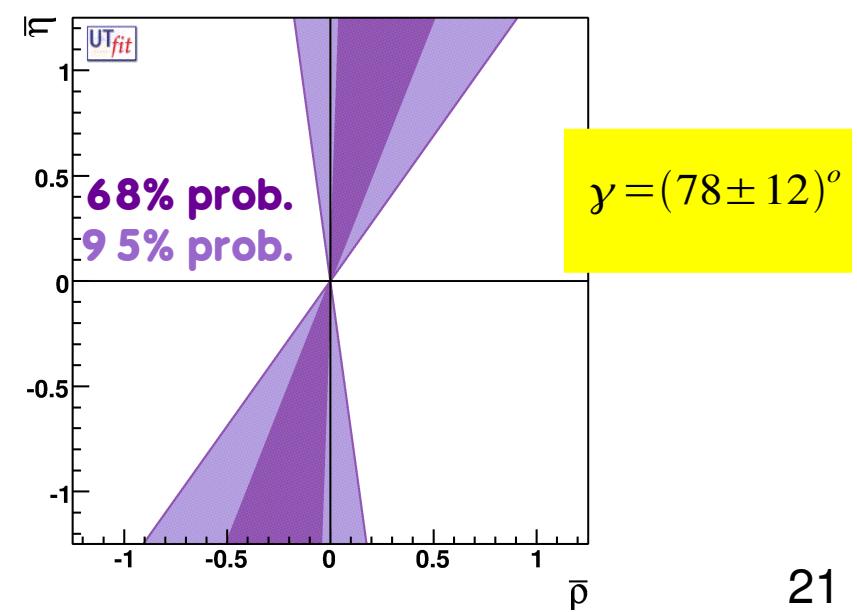
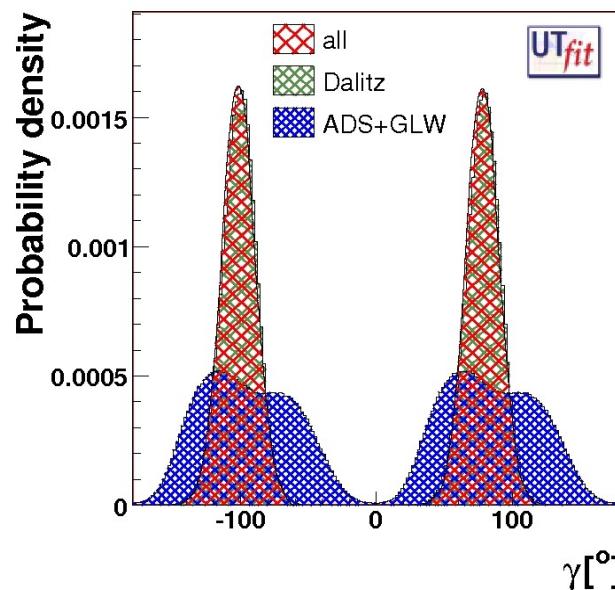
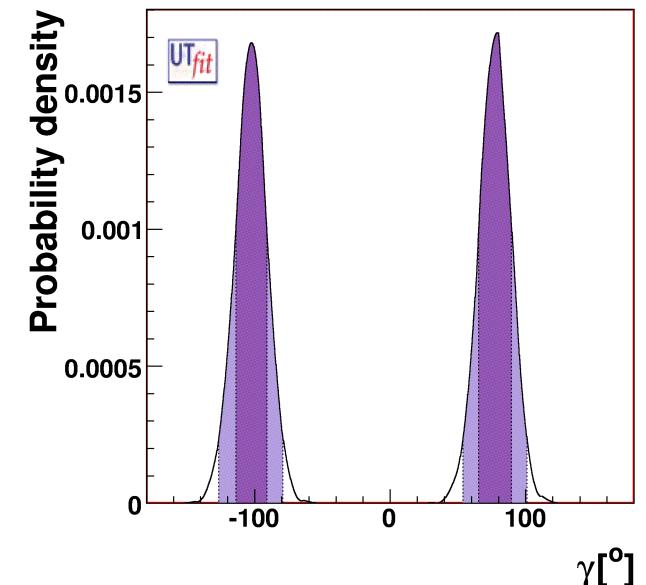
$D^0 (\bar{D}^0) \rightarrow K^- \pi^+, K^- \pi^+ \pi^0$

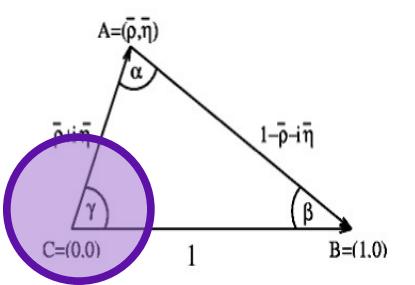
ADS

$D^0 (\bar{D}^0) \rightarrow K_S \pi \pi, \pi \pi \pi^0$

DALITZ

overall constraint:

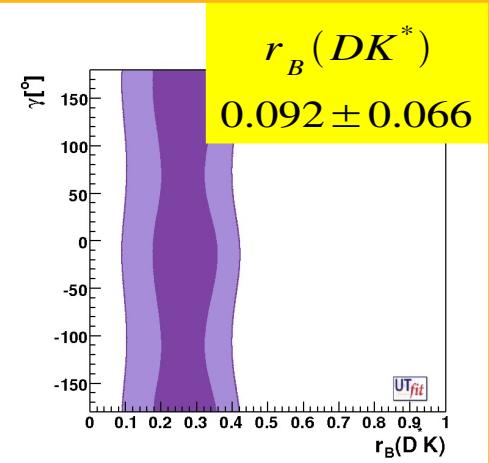
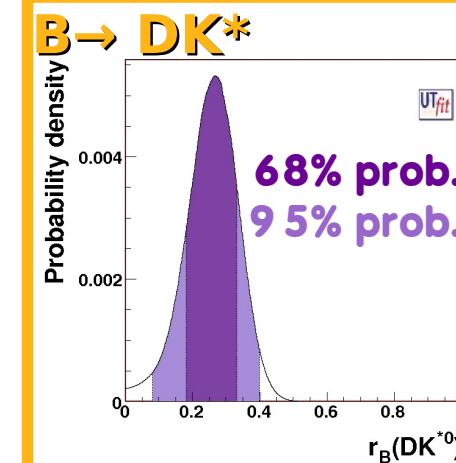
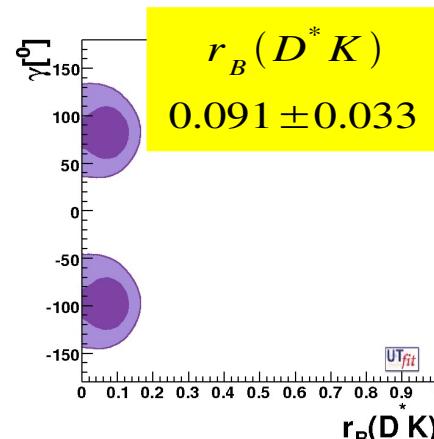
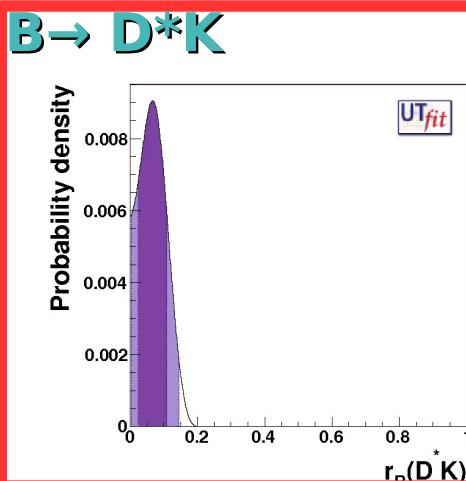
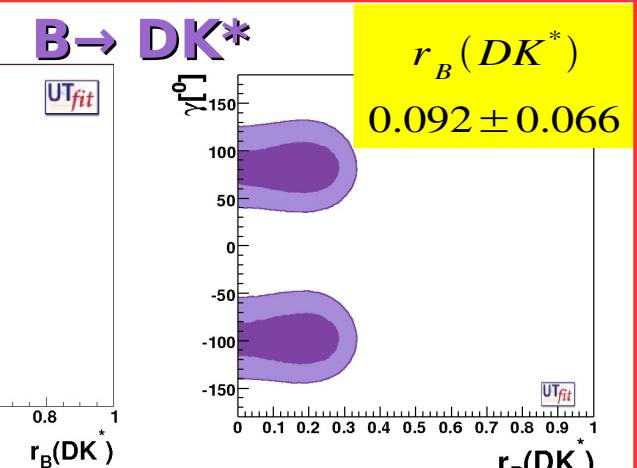
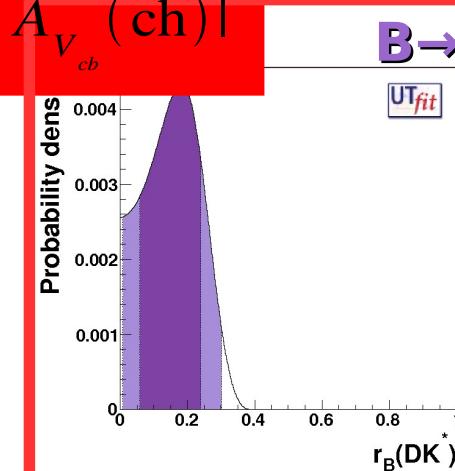
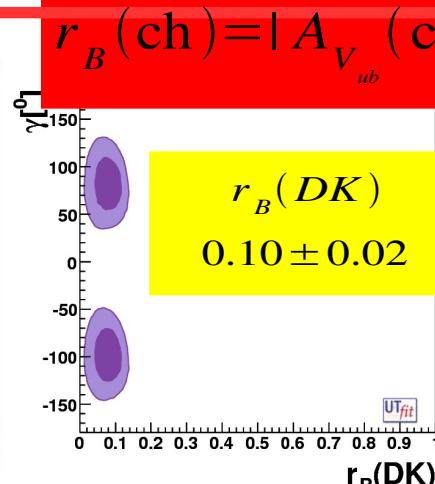
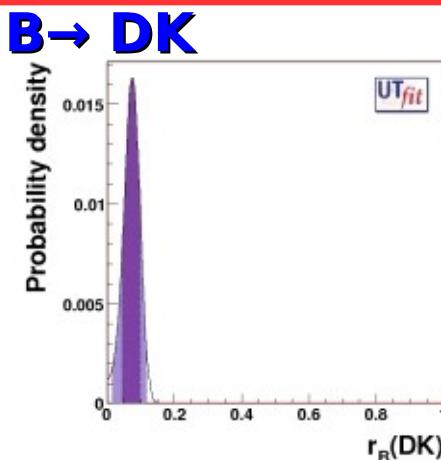




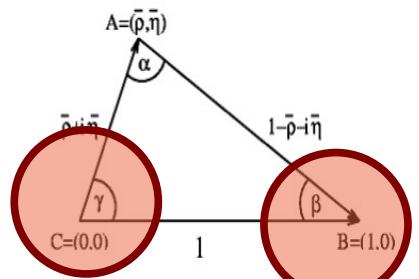
Angles, inputs

Sensitivity to γ proportional to an important parameter:

CHARGED B



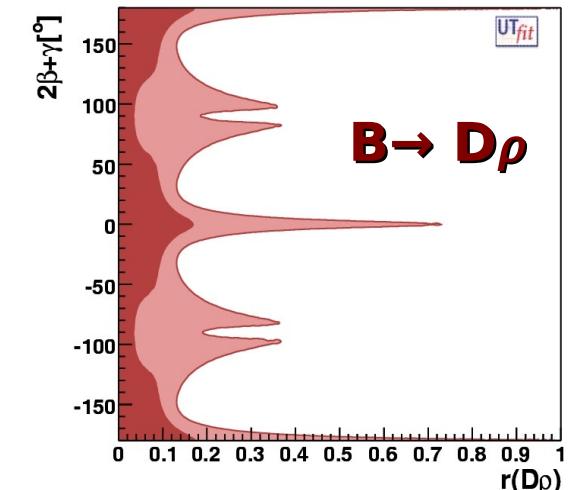
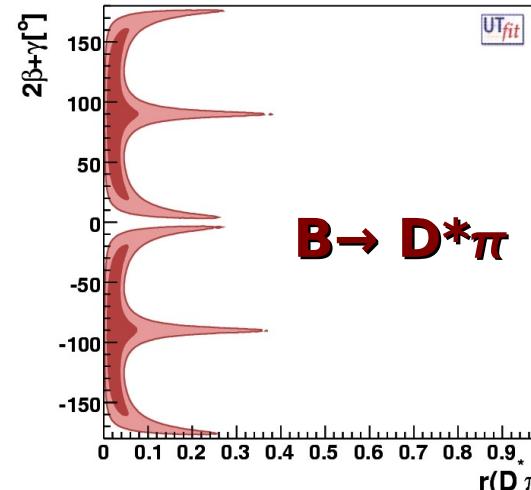
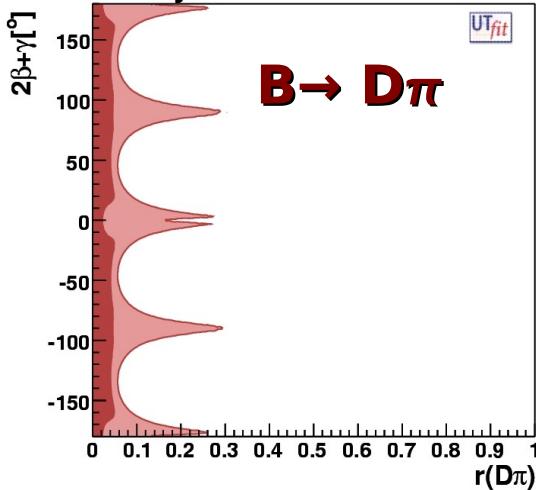
$$r_B(\text{neut}) = |A_{V_{ub}}(\text{neut})/A_{V_{cb}}(\text{neut})|$$



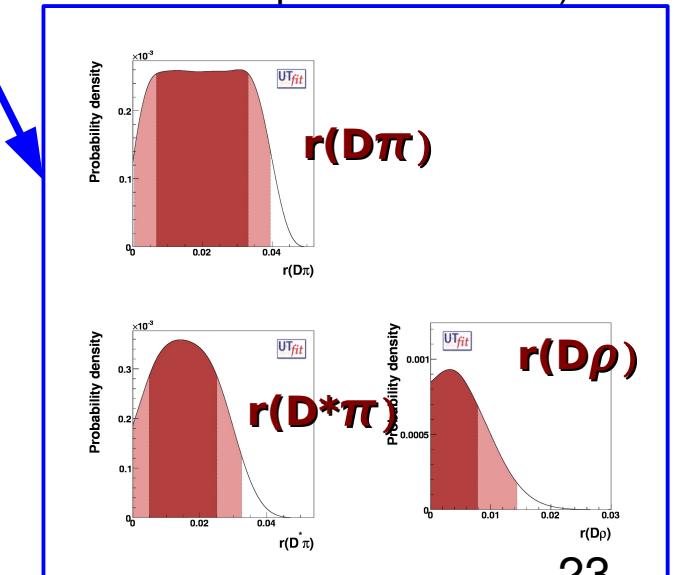
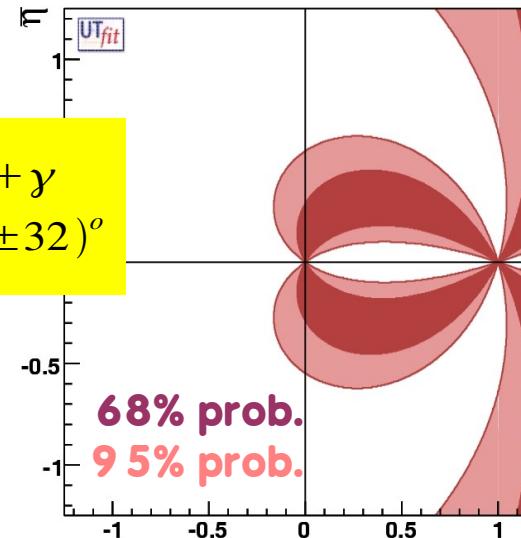
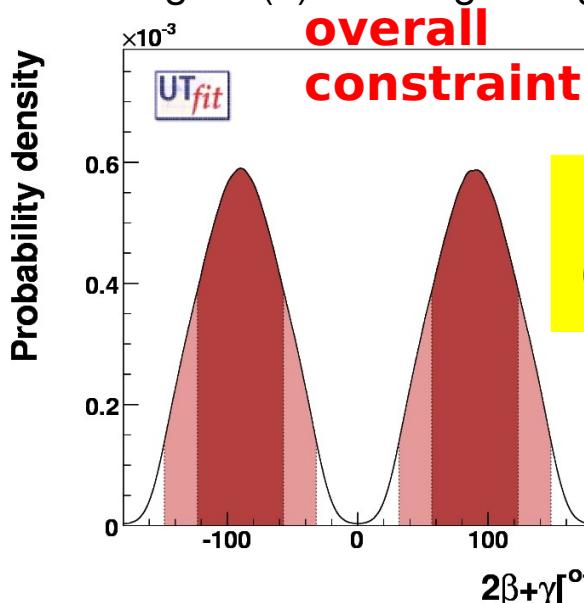
Angles, inputs

$2\beta + \gamma$: from the time dependent analysis of $B^0 \rightarrow D(\ast)\pi$ and $B^0 \rightarrow D\rho$.

The only information we can extract from data is the 2D distributions:



Assuming SU(3) and neglecting annihilations (+-100% error convoluted with the experimental one):



New physics in B_d sector

