Status of the Unitarity Triangle analysis in the Standard Model

Viola Sordini, on behalf of the UTfit collaboration

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Outline

- CP violation in the SM: the CKM mechanism
- UTfit: method and inputs
- Inputs from Unitarity Triangle, sides + ε_K measurements
- Inputs from Unitarity Triangle angles measurements
- Actual constraint on the CKM parameters from all measurements
- Compatibility plots
- Tension in the fit?
- UTfit and lattice QCD
- Conclusions

CP violation and CKM matrix

SM: CPV irreducible phase in the CKM matrix

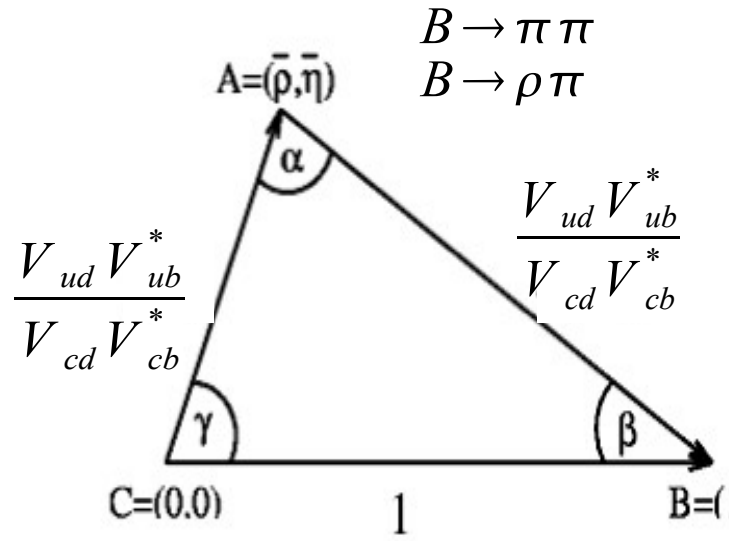
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \rightarrow V_{CKM} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^5)$$

UNITARITY

$$V_{CKM}V_{CKM}^{+} = V_{CKM}^{+}V_{CKM} = 1 \rightarrow V_{ub}^{*}V_{ud} + V_{cb}^{*}V_{cd} + V_{tb}^{*}V_{td} = 0$$

B physics

UNITARITY TRIANGLE



$B \rightarrow \pi\pi$

$B \rightarrow \rho\pi$

$B^0 \rightarrow J/\Psi K_S$

$B \rightarrow DK$

(ρ, η)

Method and Inputs

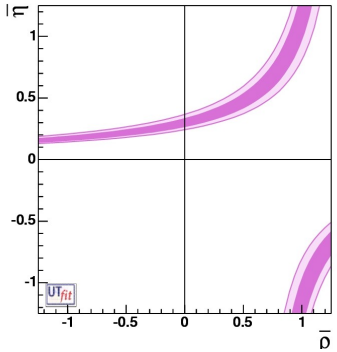
Bayes theorem

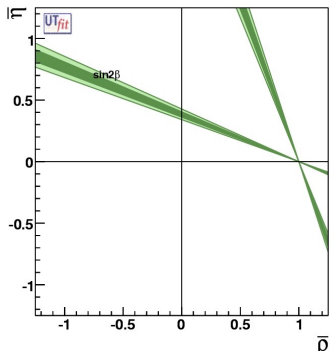
$$f(\bar{\rho},\bar{\eta},x_1,x_2..x_N|c_1,c_2...c_M)\propto$$
$$\propto\prod_{j=1}^{M} f_i(c_j|\bar{\rho},\bar{\eta},x_1,..x_N)\prod_{i=1}^{N} f_i(x_i)\,f_0(\bar{\rho},\bar{\eta})$$

with

$$x_i = B_K, f_{B_d}, \ldots$$
$$c_i = \epsilon_K, \Delta M_{d,s}, A_{CP}(J/\Psi K_S)\ldots$$

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

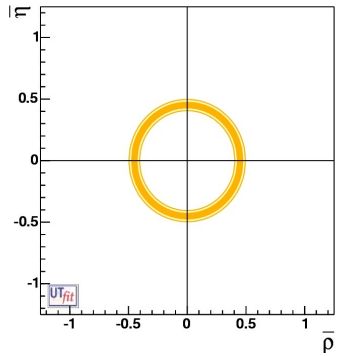


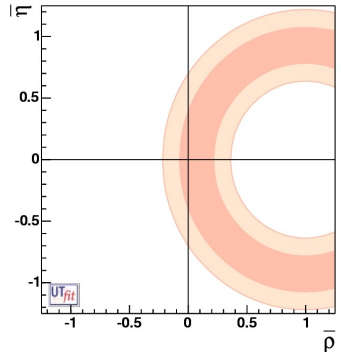


Constraints c_i ~$f_j(c_i|\rho,\eta\ldots)$ x_i

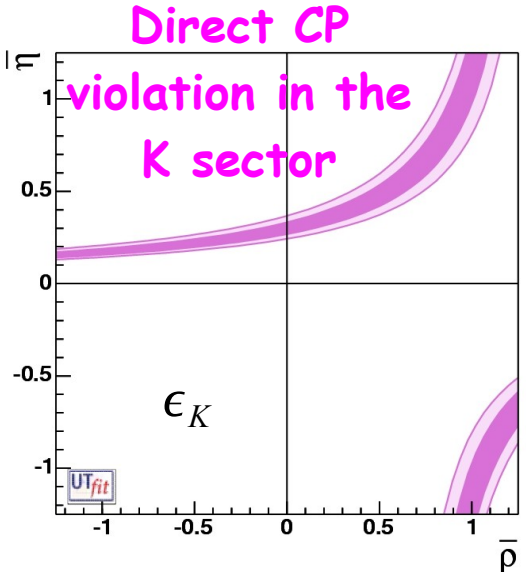
$(b\to u)/(b\to c)$	$\bar{\rho}^2+\bar{\eta}^2$	$(\bar{\Lambda}),\lambda_1,F(1)$
ϵ_K	$\bar{\eta}[(1-\bar{\rho})+P]$	B_K
$\Delta m_d, \Delta m_d/\Delta m_s$	$(1-\bar{\rho})^2+\bar{\eta}^2$	$f_B^2 B_B, \xi$
$A_{(CP)}(J/\Psi K_S)$	$\sin 2\beta$	

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

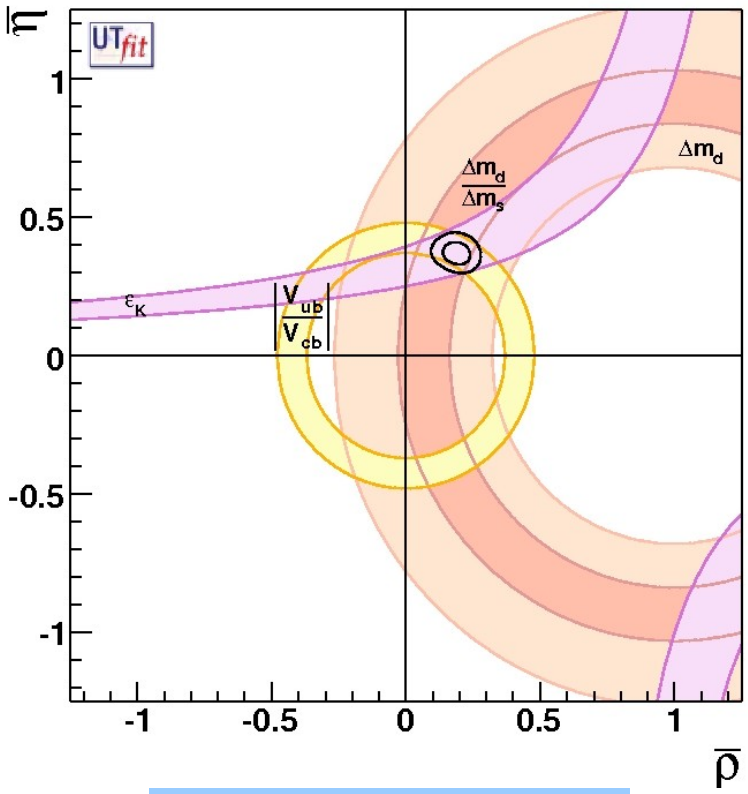


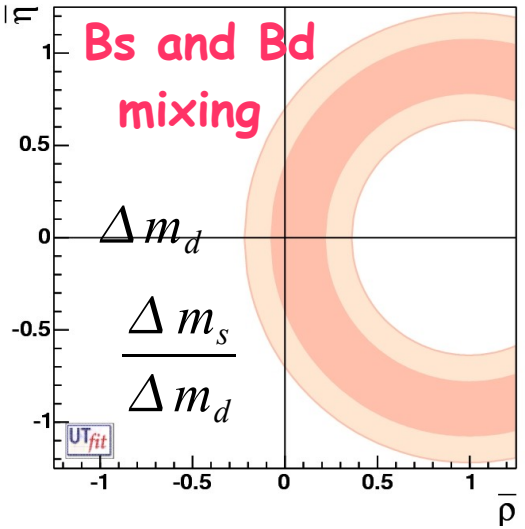


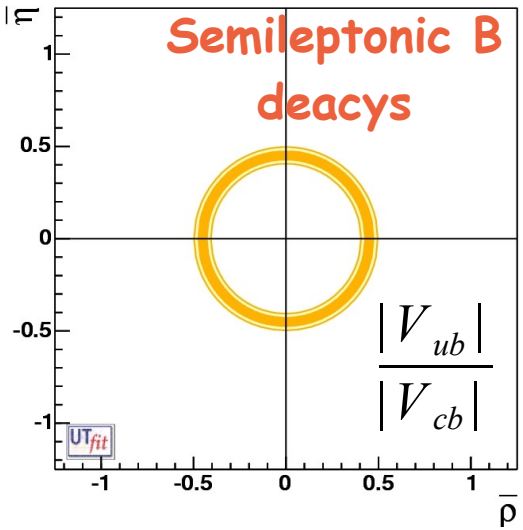
Sides + ε_K: inputs and results



LEP-time analysis (with big recent contribution from Tevatron for Dms and B-factories for Vub and Vcb)



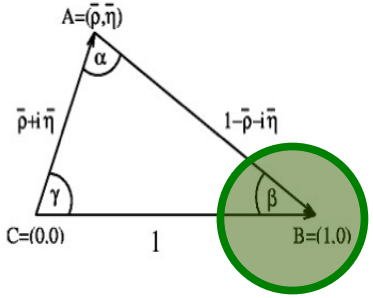




$$\bar\rho = 0.191 \pm 0.036$$
$$\bar\eta = 0.371 \pm 0.027$$

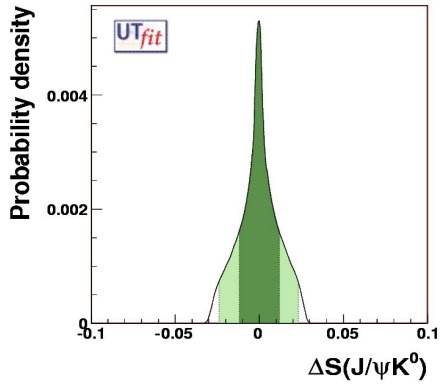
Contours at 68% and 95% probability are shown

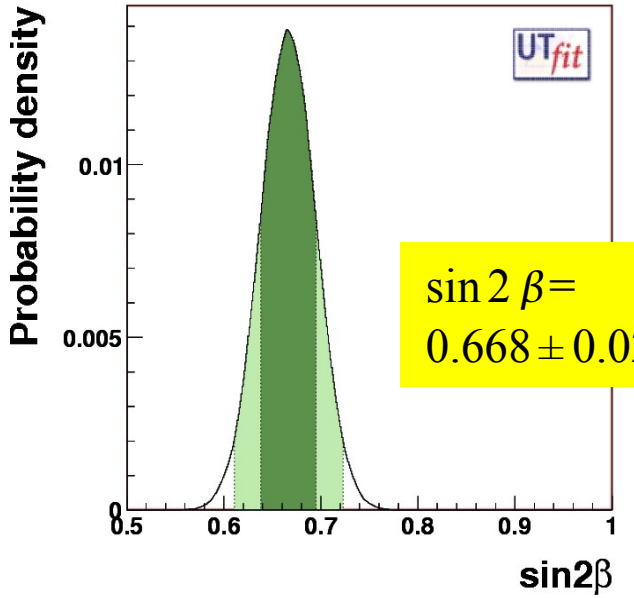
Dependence on non-perturbative hadronic parameters



Angles, inputs

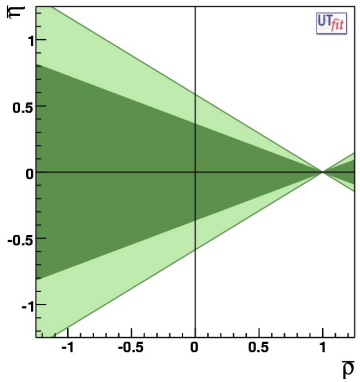
sin2 β : from the time dependent asymmetry measurement in $B^0 \to J/\Psi\ K_S$ only, theoretical error taken into account (Ciuchini et al. PRL95:221804, 2005).

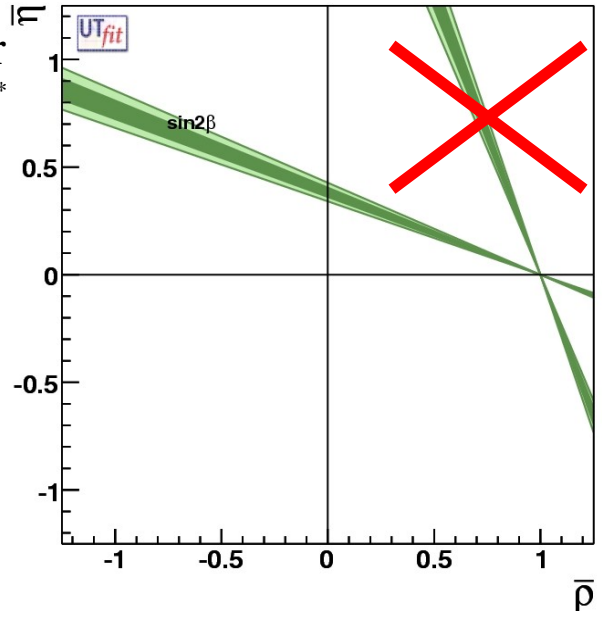


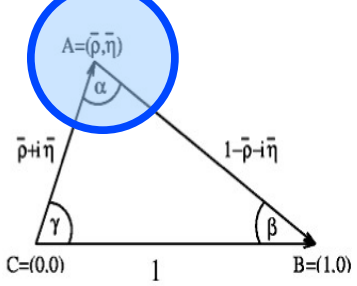


$\sin 2\beta = 0.668 \pm 0.028$

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

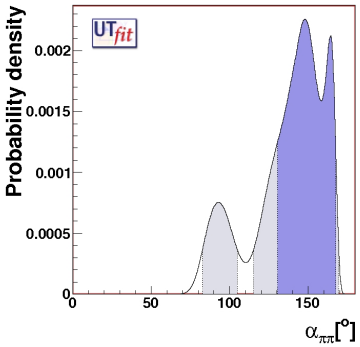


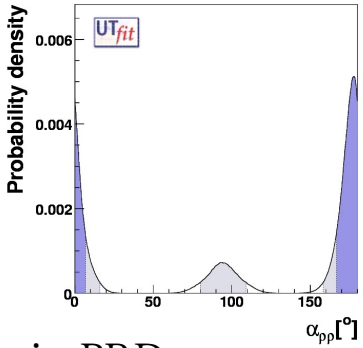




Angles, inputs

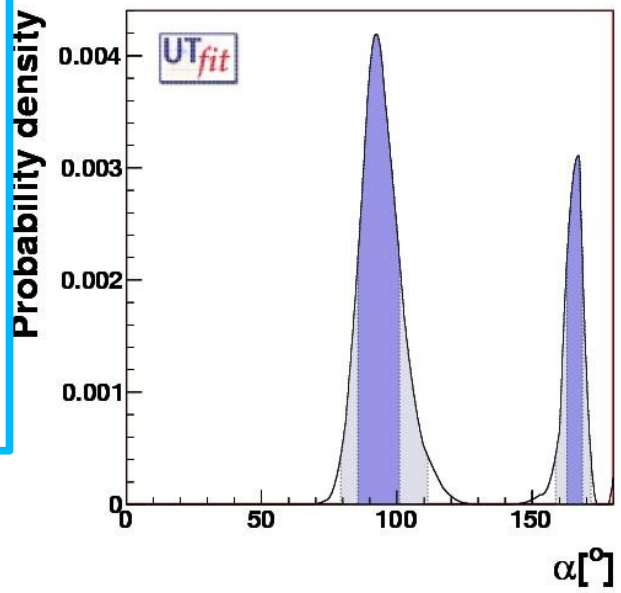
TD A_{CP} and BRs for $B \to \pi\pi$ and $B \to \rho\rho$ + isospin analysis





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

overall constraint:

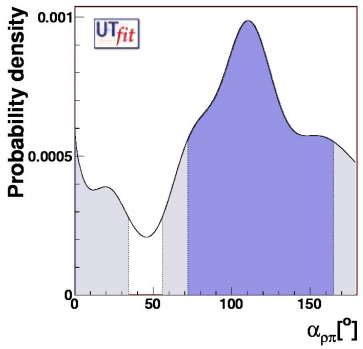


$B^0 \to (\rho\pi)^0$ analysis on the Dalitz plot.
The penguin contributions delete in:

$$A = A(B^0 \to \rho^+\pi^-) + A(B^0 \to \rho^-\pi^+) + 2A(B^0 \to \rho^0\pi^0) = (T+- + T-+ + 2T00)\, e^{-i\alpha}$$

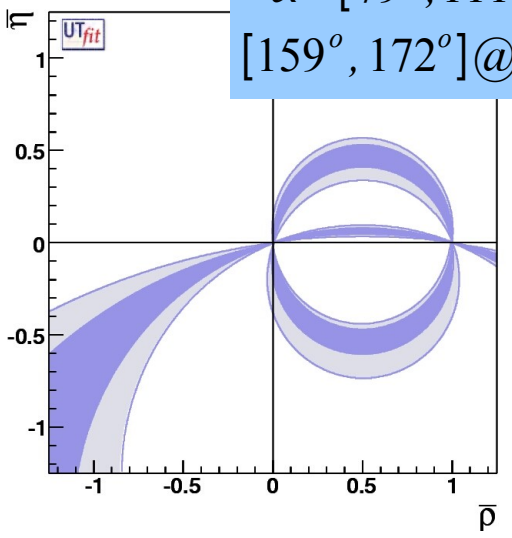
and similarly Abar, for CP conjugated.
We extract α directly from data measuring

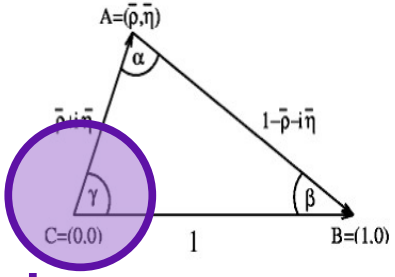
$$R = \bar{A}/A = e^{2i\alpha}$$



Penguin contributions cancel out in the sum: non need to fit for them.
As for gamma from Bs (Ciuchini et al. Phys.Lett.B645:201-203,2007)

$\alpha = [79^o, 111^o] \cup [159^o, 172^o]$ @ 95%





Angles, inputs

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

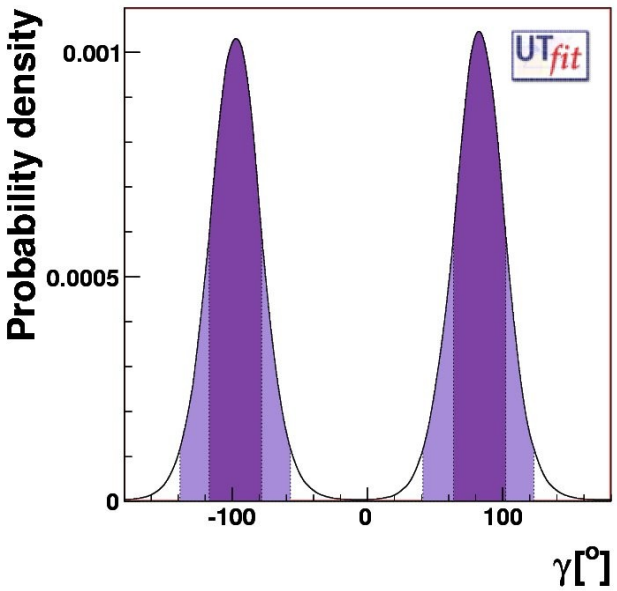
$B^{+} \to D^{(*)0}(D^{(*)0})K^{(*)+}$ decays can proceed both through V_{cb} and V_{ub} amplitudes

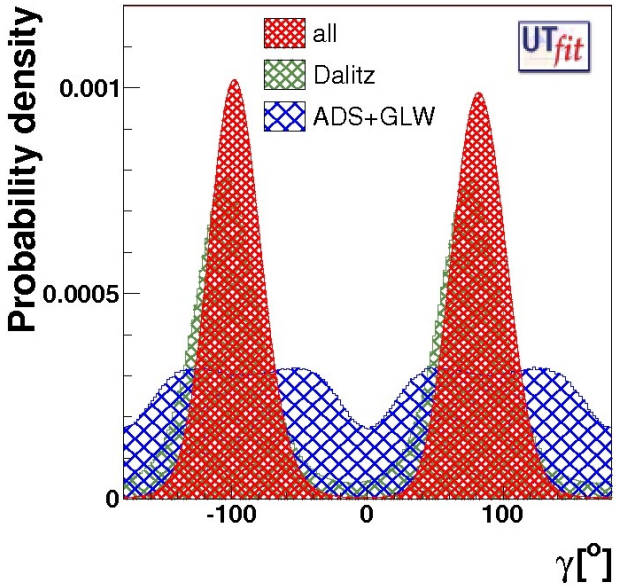
$D^{0}(\bar{D}^{0}) \to K_S \pi^{0}, K^{+}K^{-}, \pi^{+}\pi^{-}$ **GLW**

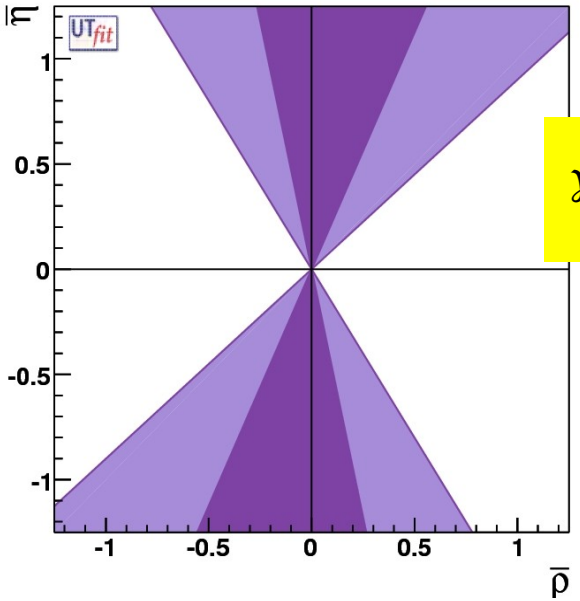
$D^{0}(\bar{D}^{0}) \to K^{-}\pi^{+}, K^{-}\pi^{+}\pi^{0}$ **ADS**

$D^{0}(\bar{D}^{0}) \to K_S \pi\pi, \pi\pi\pi^{0}$ **DALITZ**

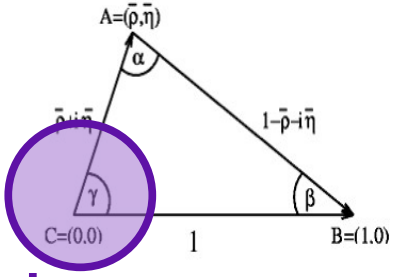
overall constraint:







$$\gamma = (83 \pm 19)^{o}$$

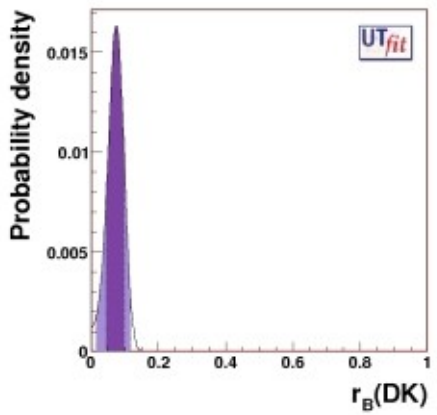


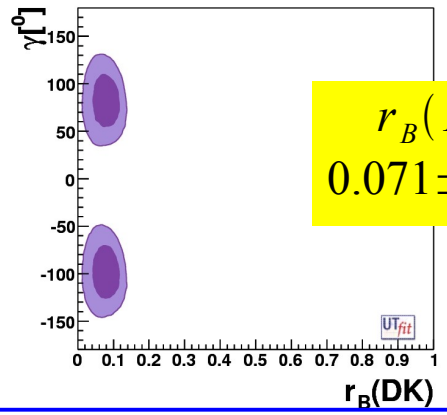
Angles, inputs

Sensitivity to γ proportional to an important parameter

FOR EACH CHANNEL $r_B(\mathrm{ch}) = |A_{V_{ub}}(\mathrm{ch}) / A_{V_{cb}}(\mathrm{ch})|$

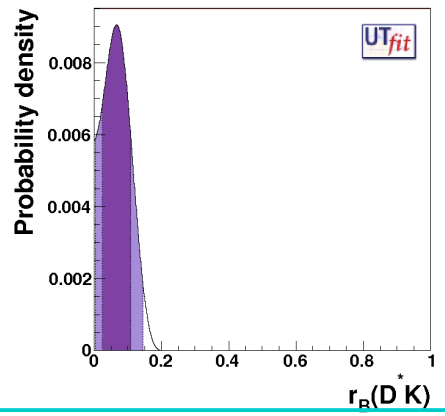
B→ DK

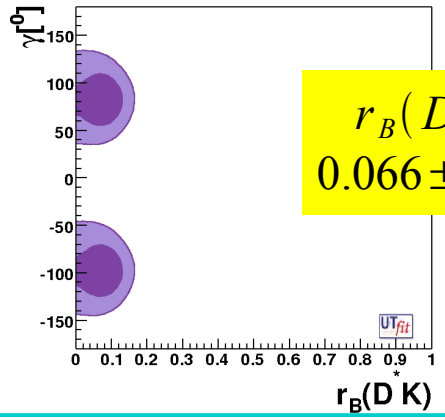




$r_B(DK)$
0.071 ± 0.024

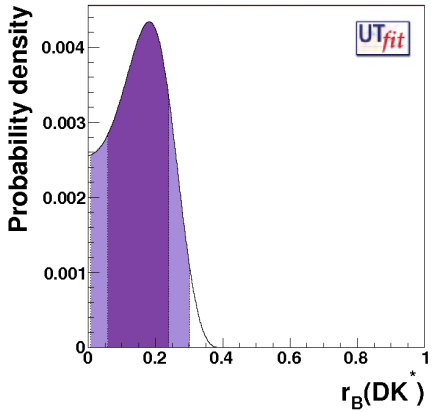
B→ D*K

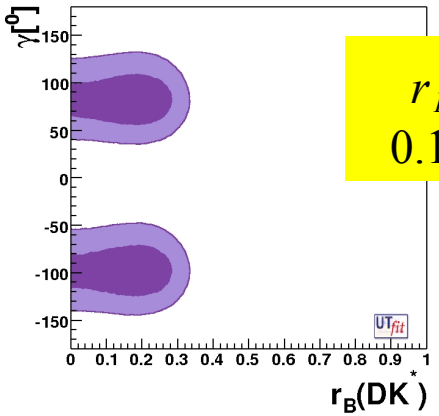




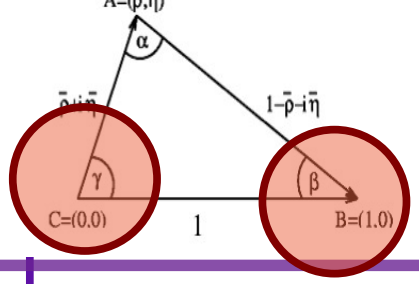
$r_B(D^*K)$
0.066 ± 0.042

B→ DK*



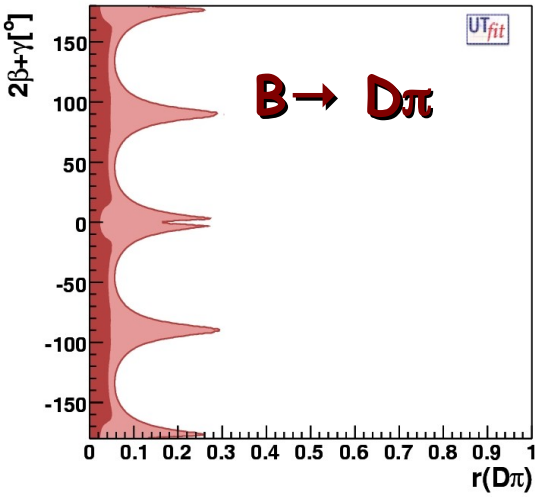


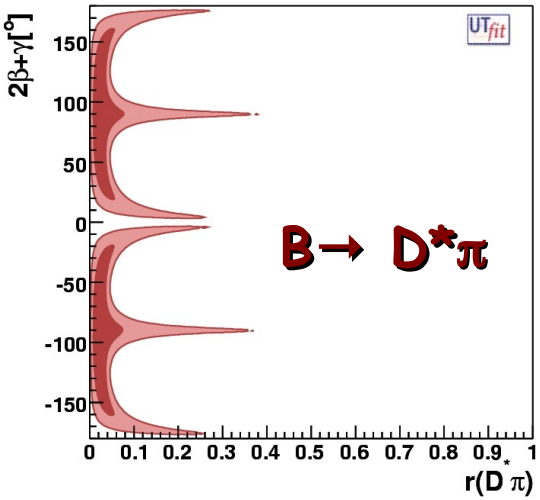
$r_B(DK^*)$
0.15 ± 0.09

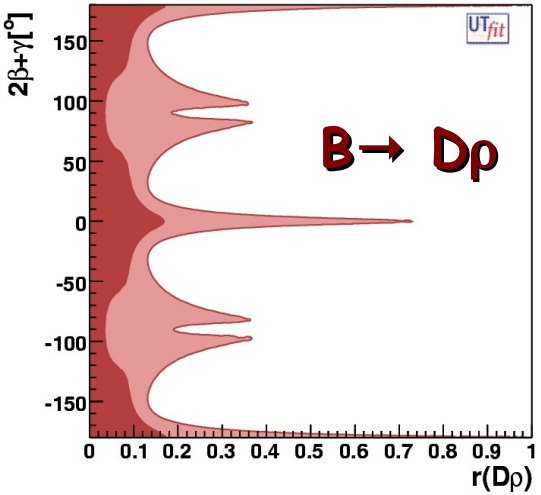


Angles, inputs

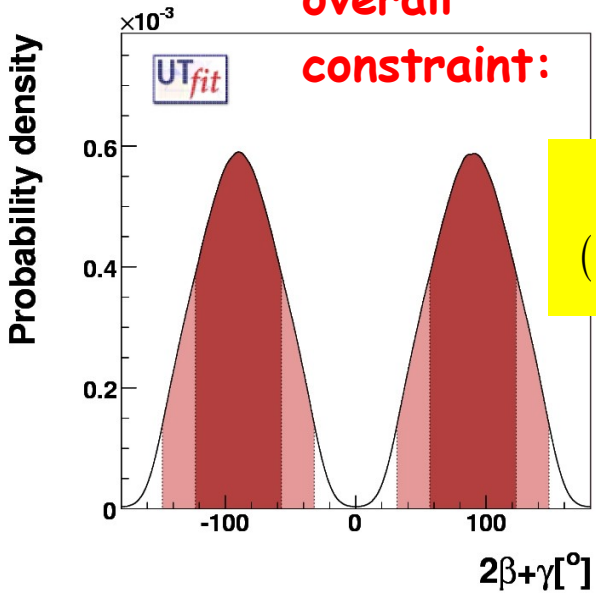
$2\beta+\gamma$: from the time dependent analysis of $B^0 \to D(*)\,\pi$ and $B^0 \to D\rho$.
The only information we can extract from data is the 2D distributions:



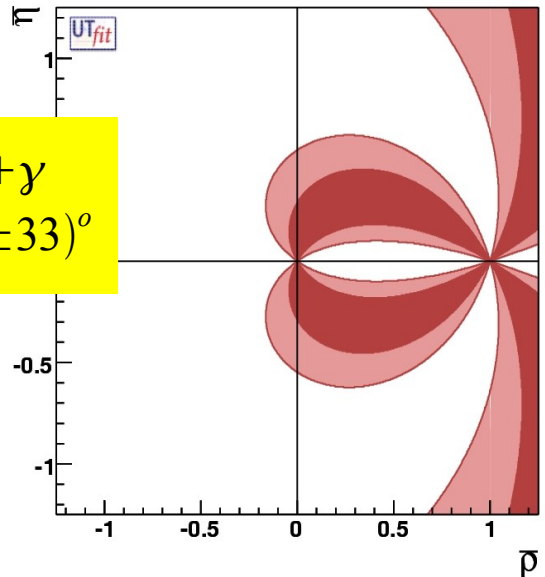


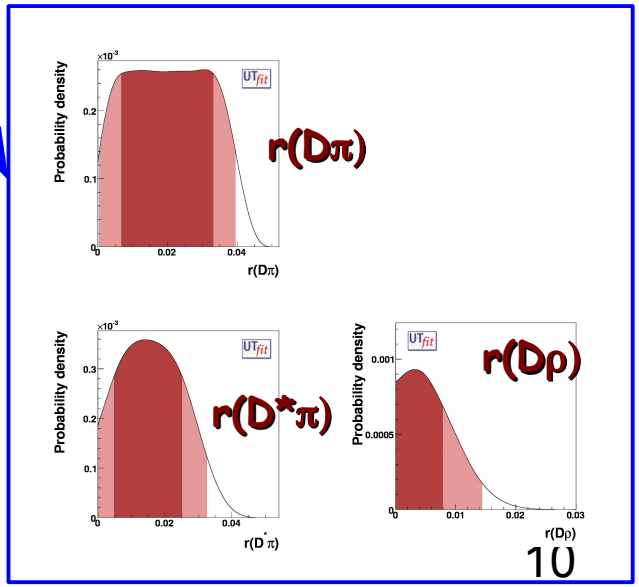


Assuming SU(3) and neglecting annihilations (+-100% error convoluted with the experimental one):

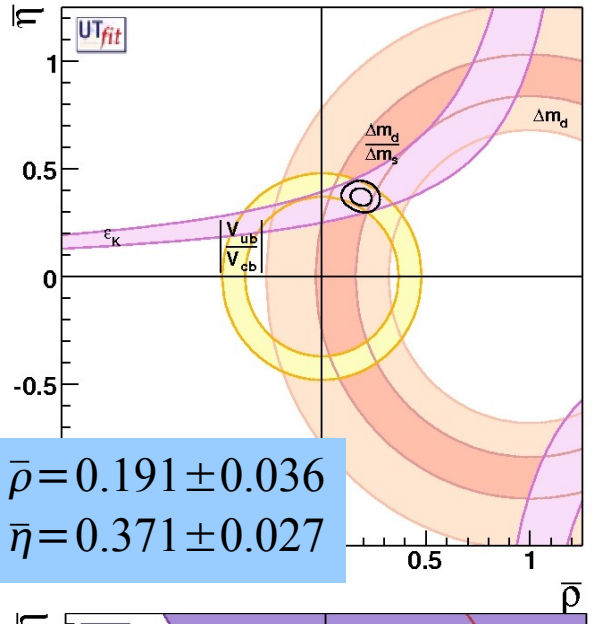


$$2\beta+\gamma$$
$$(\pm 90 \pm 33)^o$$

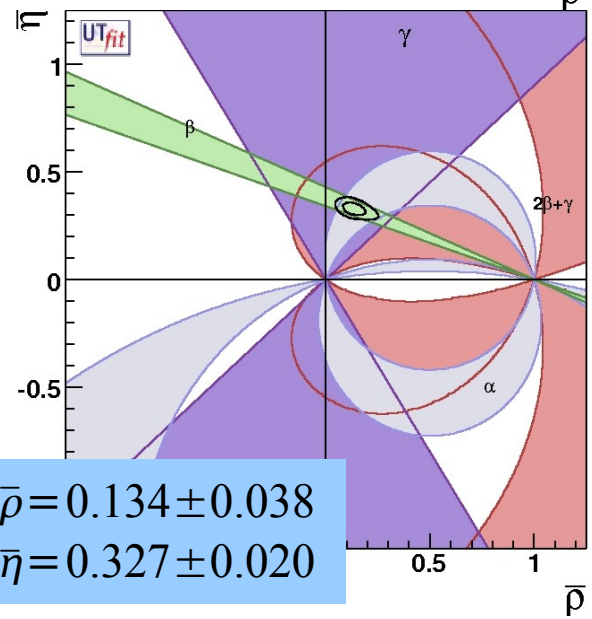




Results



$\bar{\rho} = 0.191 \pm 0.036$
$\bar{\eta} = 0.371 \pm 0.027$



$\bar{\rho} = 0.134 \pm 0.038$
$\bar{\eta} = 0.327 \pm 0.020$

NP should appear as "corrections" to the CKM pictures

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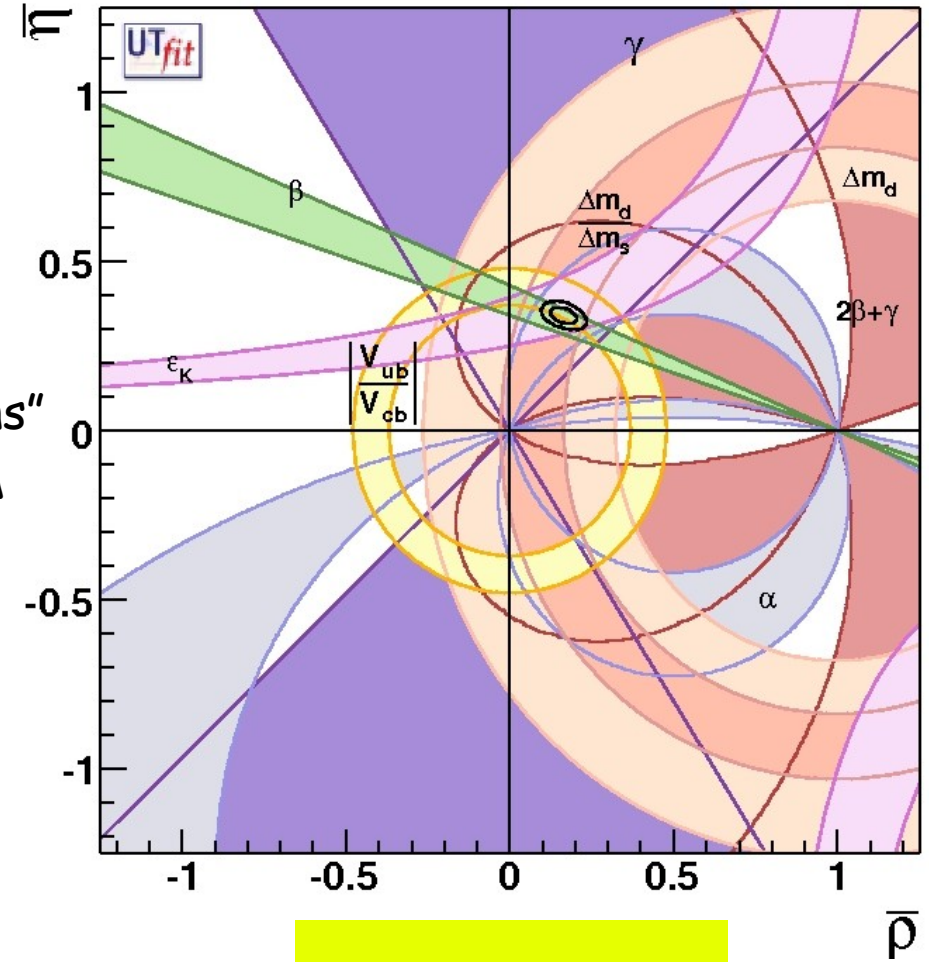
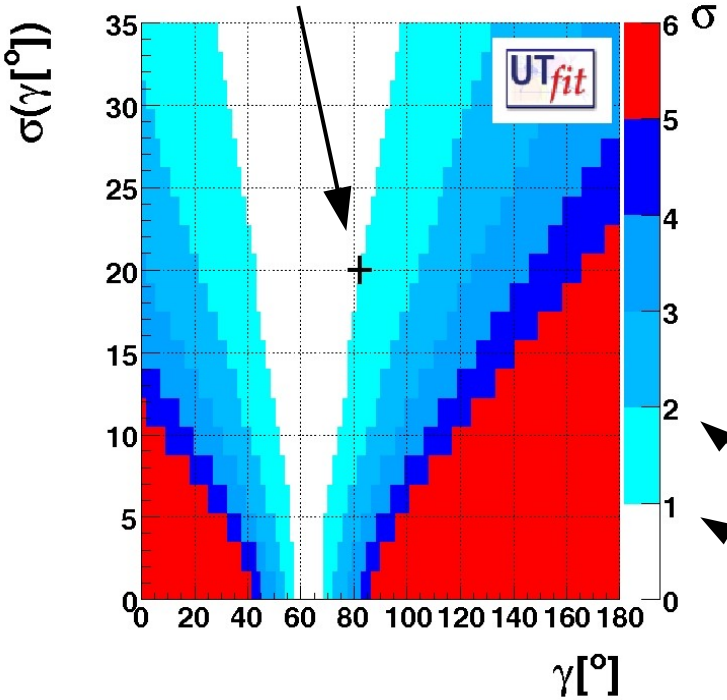


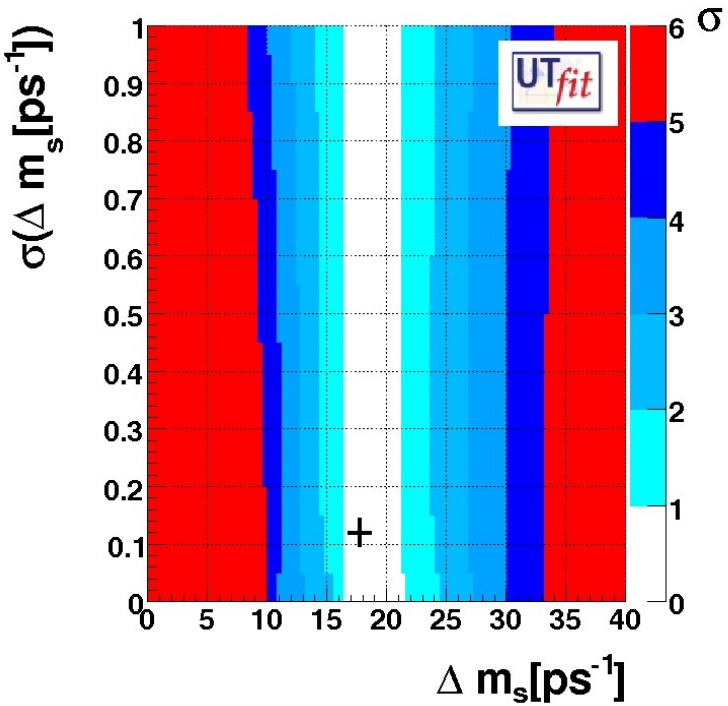
$\bar{\rho} = 0.164 \pm 0.028$
$\bar{\eta} = 0.340 \pm 0.016$

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

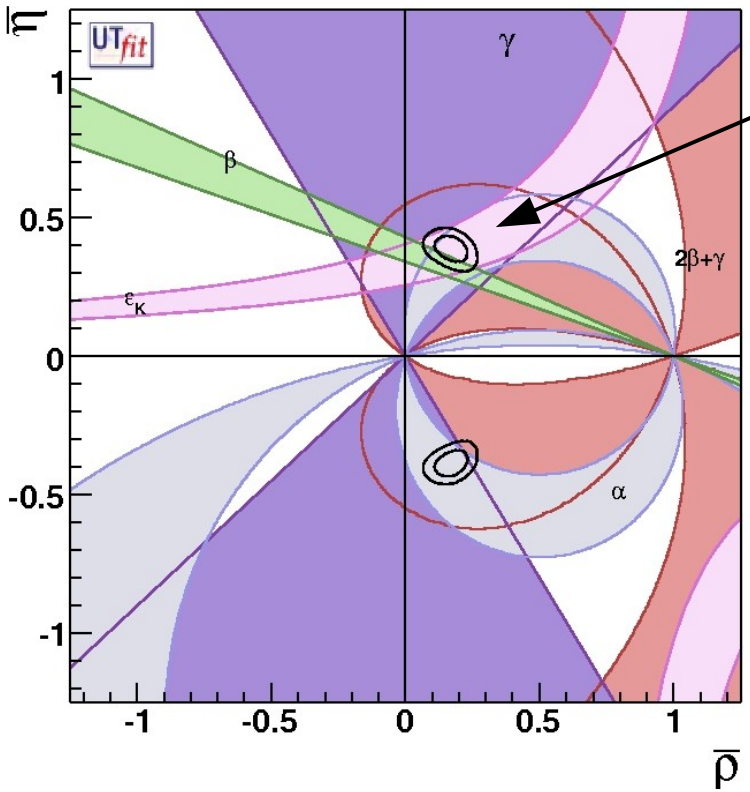
The cross has the coordinates (x,y)=(central value, error) of the direct measurement



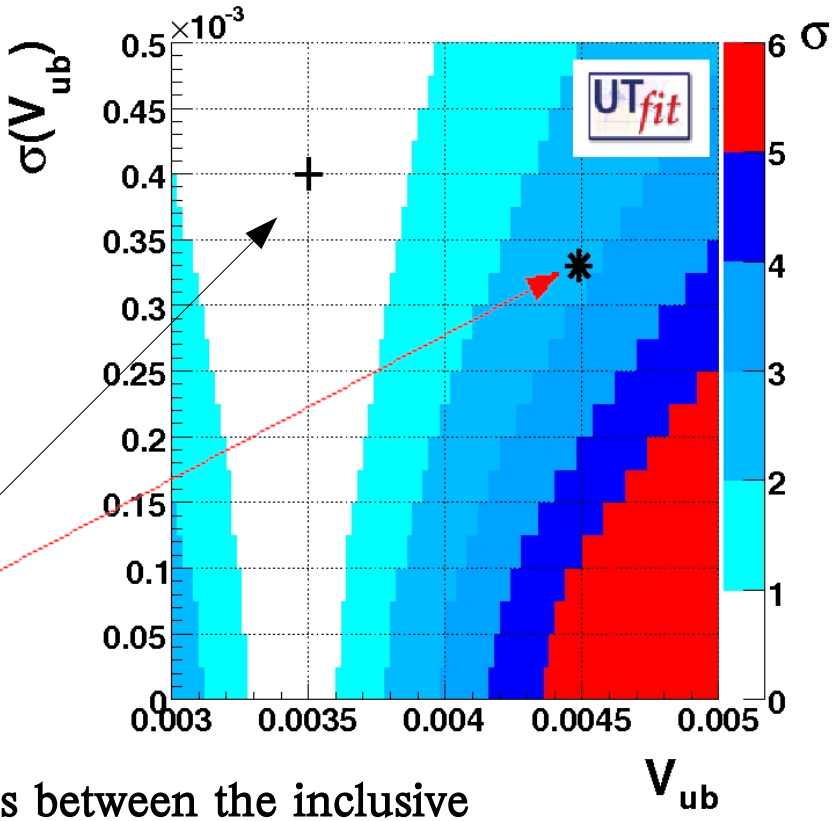


Color code: agreement between the predicted values and the measurements at better than 1, 2...nσ

Tension in the fit?



Contours (68% and 95%) for the vertex position determined by Δms/Δmd, |Vub/Vcb|



$$V_{ub}^{\text{INDIRECT}} = (3.48 \pm 0.20)\,10^{-3}$$

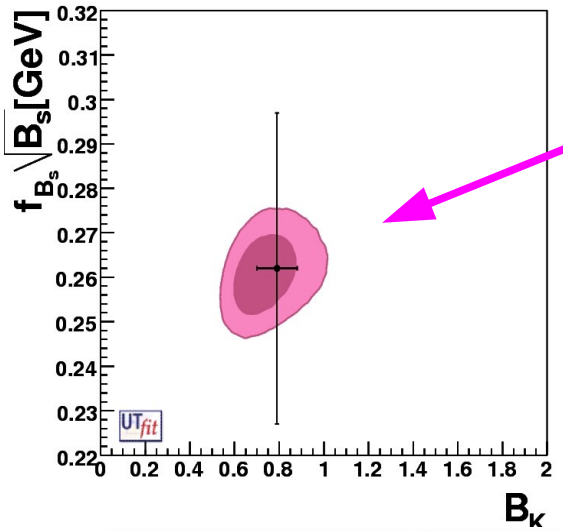
$$V_{ub}^{\text{Inclusive}} = (4.49 \pm 0.33)\,10^{-3}$$

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

the tension is between the inclusive measurement and the rest of the fit. Exclusive measurement still limited by LQCD

UTfit vs lattice QCD (I)

The fit is overconstrained, we can **extract hadronic parameters** from it (assuming the SM)



Using the constraints from angle measurements and |Vub/Vcb| to determine CKM parameters and Δmd, Δms, and ε_K to determine the LQCD quantities

A UT analysis without relying on theoretical calculations of hadronic matrix elements is possible

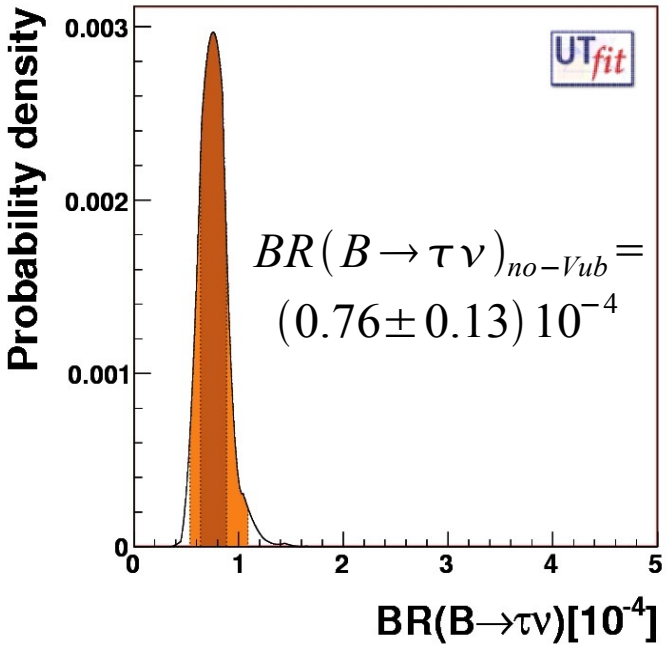
Main goal: identify where lattice QCD calculation improvements are necessary

Parameter	UT*angle*	UT*angle* + V_{ub}/V_{cb}	lattice QCD results
B_K	0.78 ± 0.09	0.75 ± 0.09	$0.79 \pm 0.04 \pm 0.08$
$f_{B_s}\sqrt{B}_{B_s}$ (MeV)	262 ± 6	261 ± 6	262 ± 35
ξ	1.25 ± 0.06	1.24 ± 0.08	1.23 ± 0.06
f_{B_d} (MeV)	186 ± 11	187 ± 13	189 ± 27
f_{B_s} (MeV)	232 ± 9	231 ± 9	230 ± 30

M.Bona et al. JHEP 0610:081, 2006 (hep-ph/0606167)

f_B-free prediction of $B \to \tau\nu$

Adding to this fit the information on the Bd Bag parameter, B_{Bd} = 1.28+− 0.05 +− 0.09 (S.Hashimoto, hep−ph/(0411126)), we can predict BR($B \to \tau\nu$) without assuming any f_B value from lattice calculation.



$$BR(B \to \tau\nu)_{All} = (0.90 \pm 0.16)\,10^{-4}$$
$$BR(B \to \tau\nu)_{Vub-Incl.} = (0.96 \pm 0.20)\,10^{-4}$$
$$BR(B \to \tau\nu)_{Vub-Excl.} = (0.76 \pm 0.12)\,10^{-4}$$

CORRELATION WITH Vub!

Same Vub dependence observed in:

$$\Delta m_{sexp} = (17.77 \pm 0.12)\,\mathrm{ps}^{-1}$$

$$\Delta m_{sAll} = (20.9 \pm 2.6)\,\mathrm{ps}^{-1}$$
$$\Delta m_{sVub-Incl.} = (19.4 \pm 2.5)\,\mathrm{ps}^{-1}$$
$$\Delta m_{sVub-Excl.} = (21.7 \pm 2.8)\,\mathrm{ps}^{-1}$$

Attention: those are the inputs used in MFV fit!

G.Isidori, P.Paradisi PLB 639, 499 (2006)

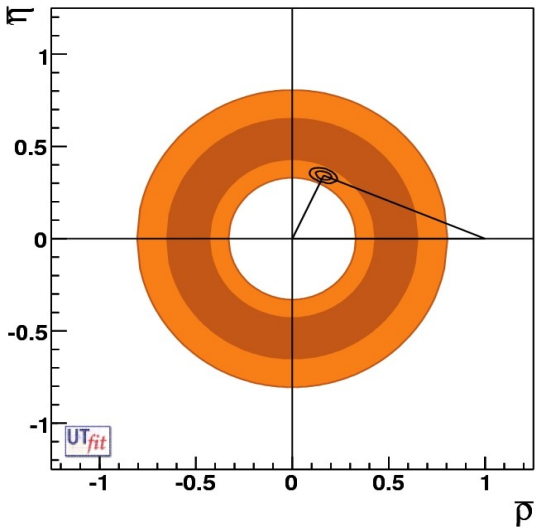
M.Carena et al. PRD74 (2006) 015009

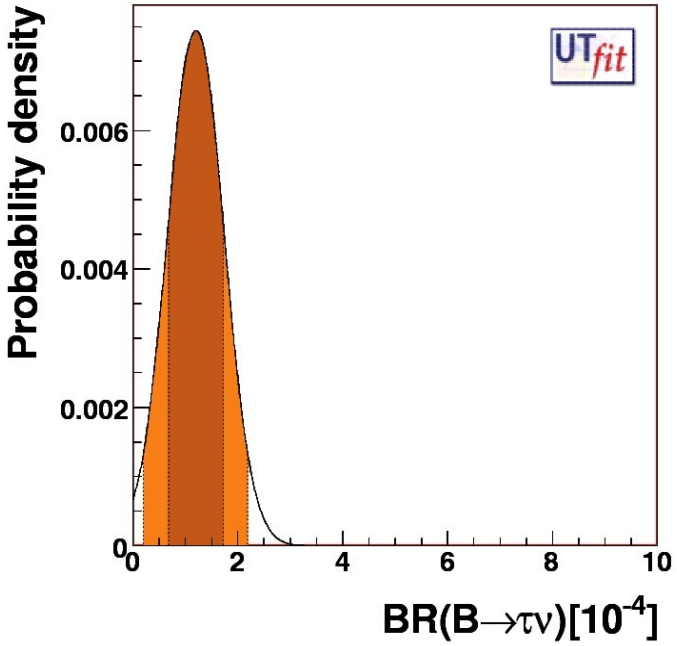
UTfit vs lattice QCD (II)

$BR(B \to \tau\nu)$

Constraint on Rb indipendent from Vub determination by semileptonic decays

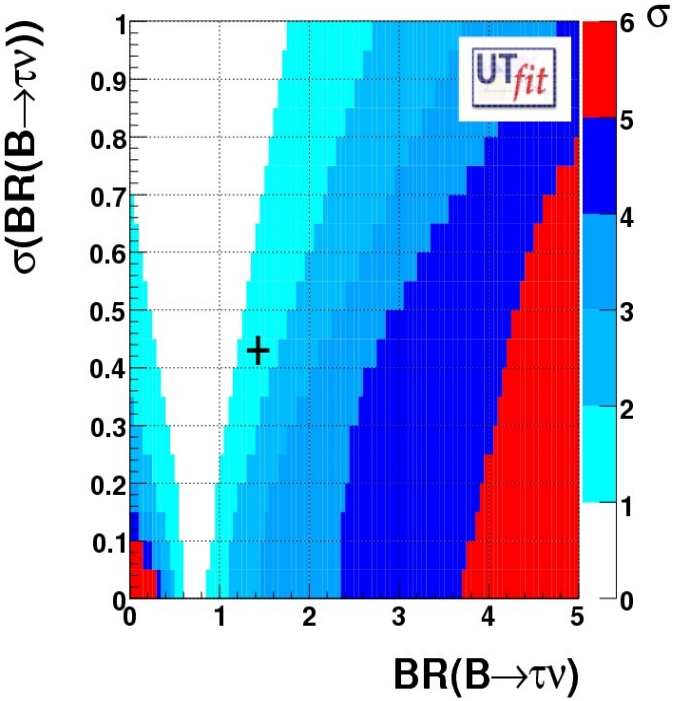
$$R_b = \sqrt{\bar{\rho}^2 + \bar{\eta}^2}$$





Experimental value (WA)

$$BR(B \to \tau\nu)_{\text{exp}} = (1.43 \pm 0.43)\,10^{-4}$$



No Vub input

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 to this

- Small tension in the fit, due to the Vub measurement

- Extraction of hadronic parameters

- Prediction of BR($B \to \tau \nu$) without relying on the lattice calculations for f_B

References

http://www.utfit.org/

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hep-ph/0701204

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A Reappraisal after the Measurements of Δm_s and BR($B \to \tau \nu$)"
JHEP 0610:081,2006 (hep-ph/0606167)

M. Bona et al. [UTfit Collaboration]
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