Status of the Unitarity Triangle in the Standard Model

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on behalf of the
UTfit Collaboration
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http://www.utfit.org

HEP2005 International Europhysics Conference on High Energy Physics, Lisboa, Portugal, July 21st 2005

The Method and the Inputs:

The experimental inputs, function of $\bar{\rho}$ and $\bar{\eta}$, are related to the $\bar{\rho}$ and $\bar{\eta}$ through the Bayes Theorem

$$f(\bar{\rho},\bar{\eta},X|c_1,\dots,c_m) \sim \prod_{j=1,m} f_j(\mathcal{C}|\bar{\rho},\bar{\eta},X) * \prod_{i=1,N} f_i(x_i) f_0(\bar{\rho},\bar{\eta})$$

$X \equiv x_1,\dots,x_n = m_t, B_K, F_B, \dots$

$\mathcal{C} \equiv c_1,\dots,c_m = \epsilon, \Delta m_d/\Delta m_s, A_{CP}(J/\psi K_S), \dots$

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

}, m_t

Standard Model +
OPE/HQET/
Lattice QCD
to go from
quarks
to hadrons

see also: M.B., UTfit talk
at the *Physics beyond the SM* session

M. Bona *et al*. (UTfit Collaboration)
JHEP07(2005) 028 hep-ph/0501199

Inputs used

flat error

New values but WA not available yet

new from HFAG

new from the Tevatron

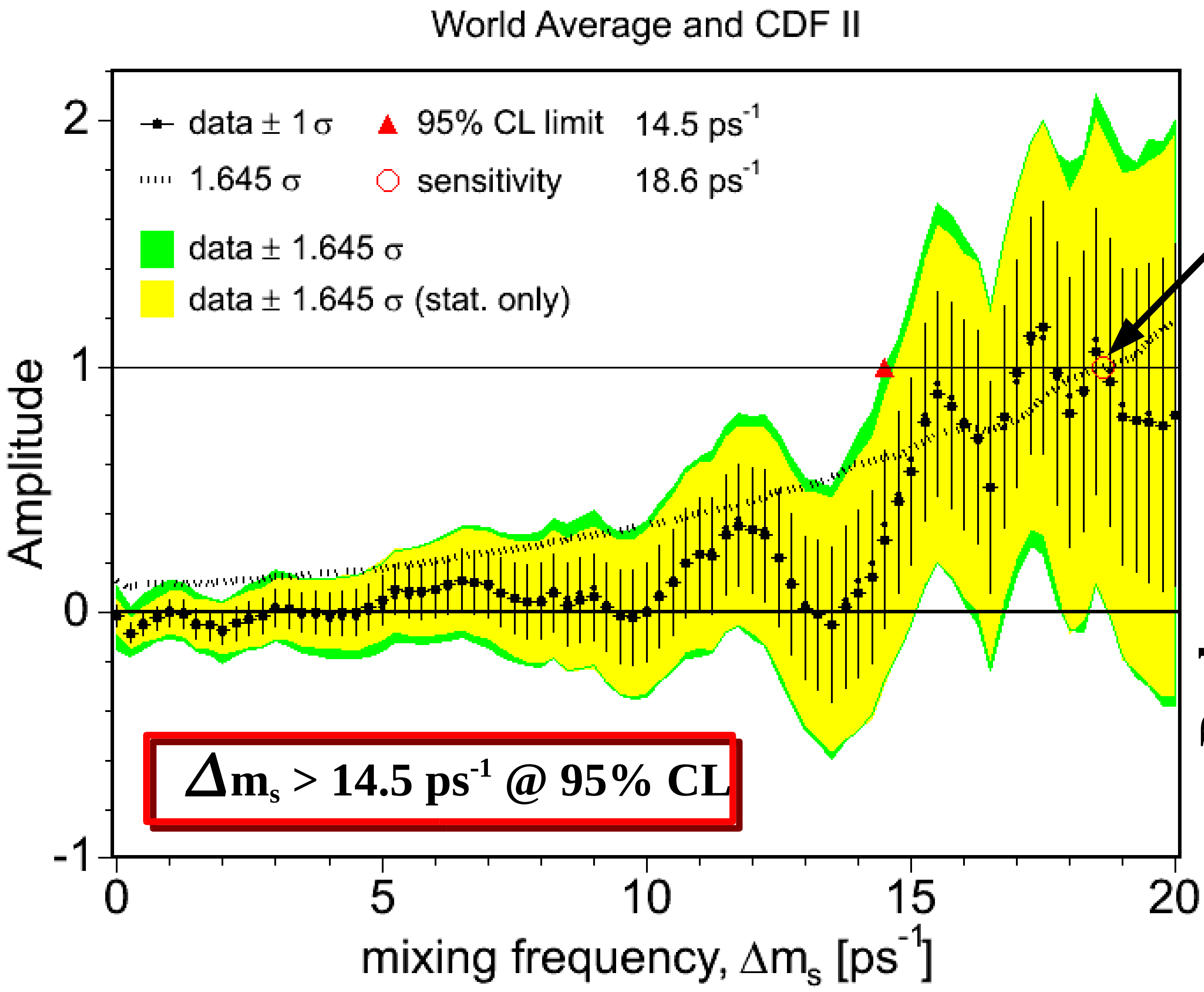
new value from LQCD

new WA

λ	0.2258 ± 0.0014	
V_{cb} inclusive	$41.6 \pm 0.7 \pm 0.6 \cdot 10^{-3}$	average from inclusive
V_{cb} exclusive	$41.4 \pm 2.1 \cdot 10^{-3}$	average from exclusive
V_{ub} inclusive LEP	$4.09 \pm 0.62 \pm 0.47 \cdot 10^{-3}$	LEP average
V_{ub} inclusive HFAG	$4.38 \pm 0.19 \pm 0.27 \cdot 10^{-3}$	LP05
V_{ub} exclusive	$3.80 \pm 0.27 \pm 0.47 \cdot 10^{-3}$	BR from HFAG + LQCD
Δm_d	$0.502 \pm 0.007\ ps^{-1}$	LEP/SLD/CDF/B-Factories
Δm_s	$> 14.5\ ps^{-1}$	LEP/SLD/CDF-1
m_t	$165.0 \pm 3.9\ GeV$	CDF/D0 (LP05)
m_c	$1.3 \pm 0.1\ GeV$	
$f_{B_s}\sqrt{\hat{B}_{B_s}}$	$276 \pm 38\ MeV$	Lattice QCD
ξ	$1.24 \pm 0.04 \pm 0.06$	Lattice QCD
B_K	$0.79 \pm 0.04 \pm 0.09$	Lattice QCD
$\sin 2\beta$	0.687 ± 0.032	B-Factories

New Likelihood for Δm_s

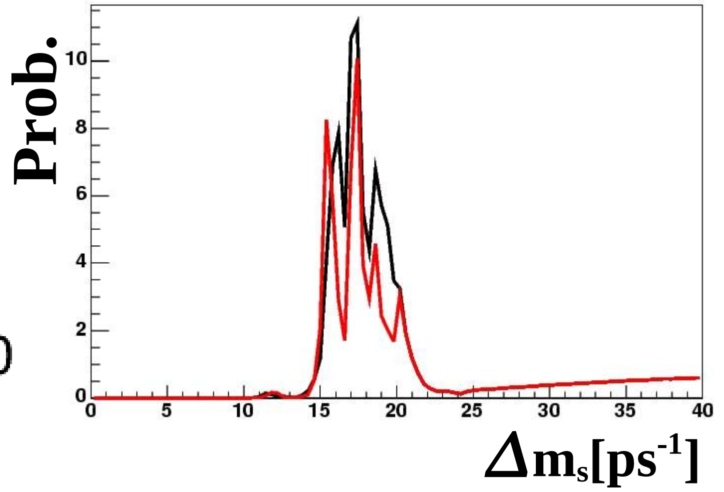
$$P_{B_q^0 \to B_q^0(\bar{B}_q^0)} = \frac{1}{2} e^{-t/\tau_q}(1 \pm A \cos \Delta m_q t)$$



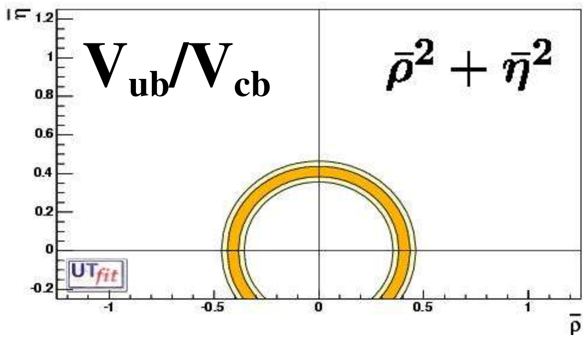
signal *hint* @ $\Delta m_s \sim 18.6\ ps^{-1}$ with ~2σ stat. significance

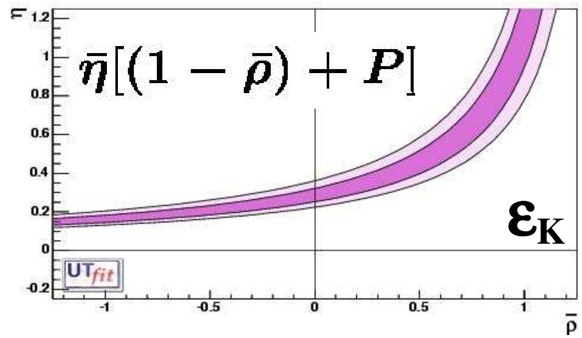
black: before CKM2005

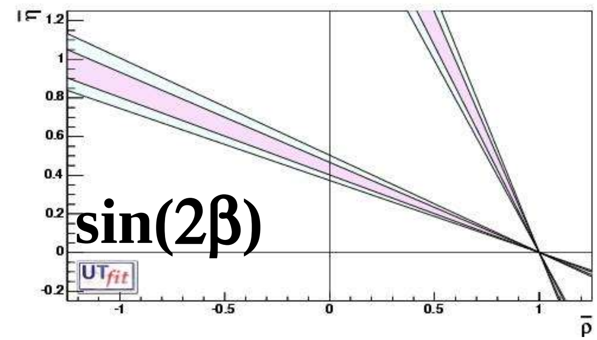
red: after CKM2005

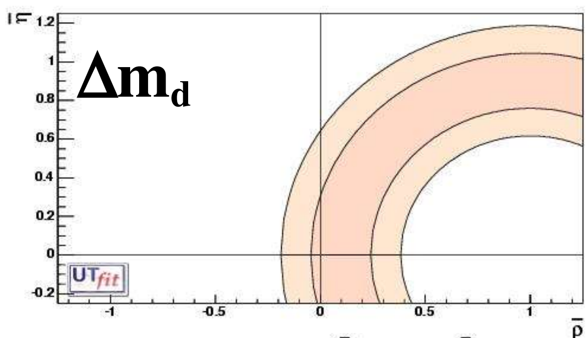


Standard constraints in the ρ-η plane:

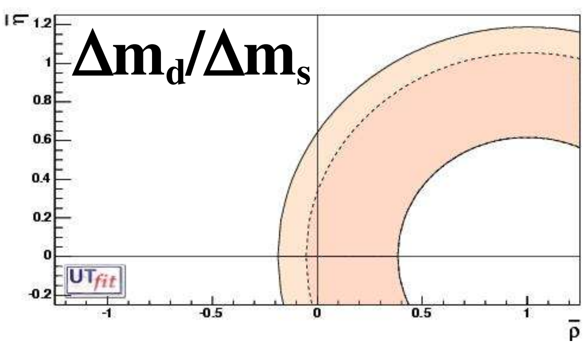


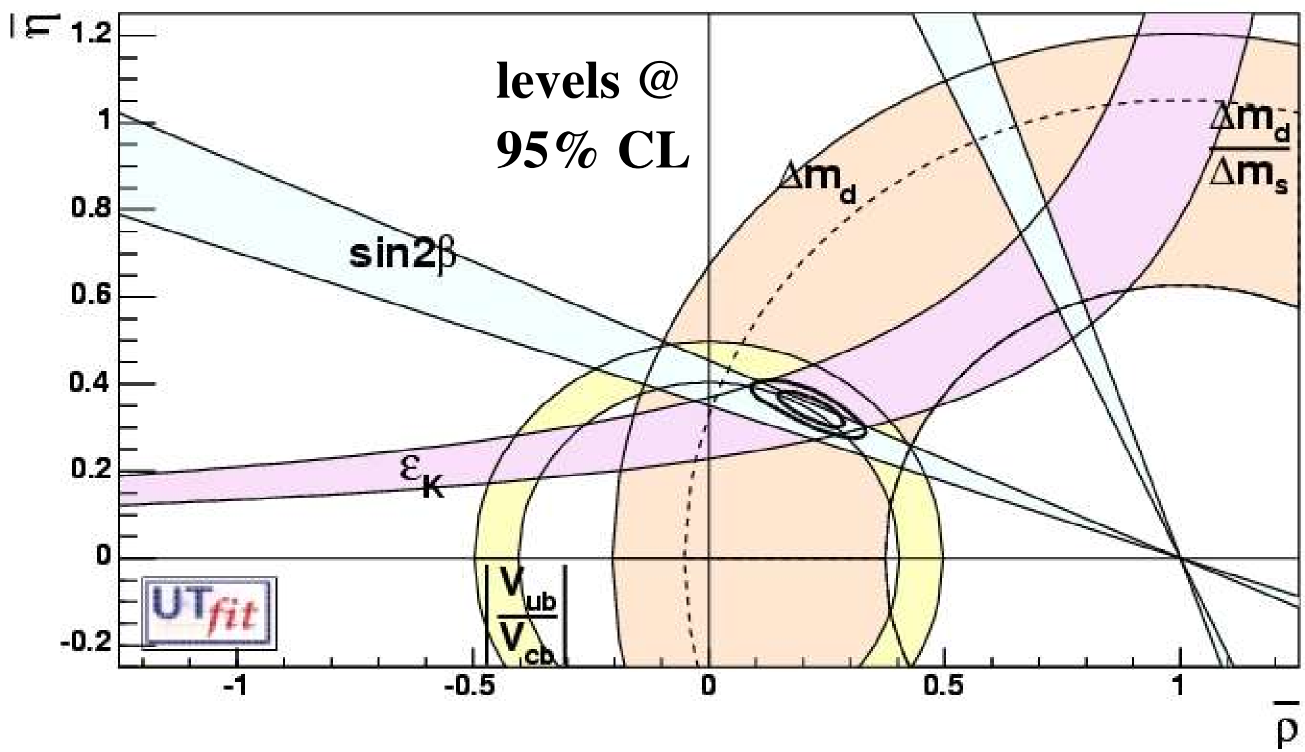






$$(1-\bar\rho)^2 + \bar\eta^2$$

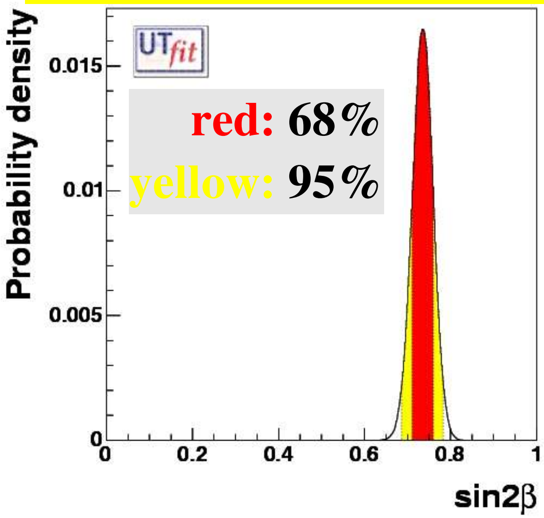


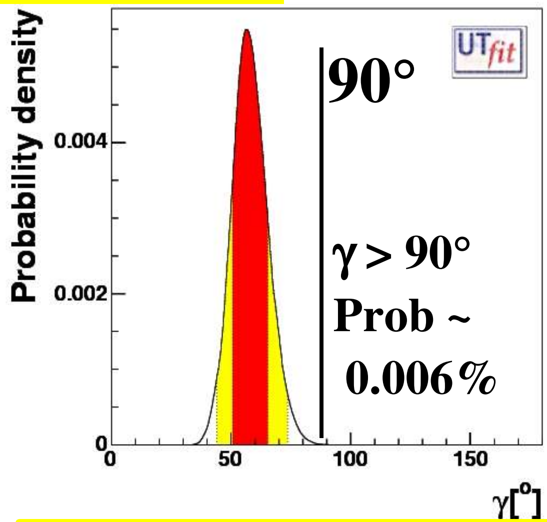


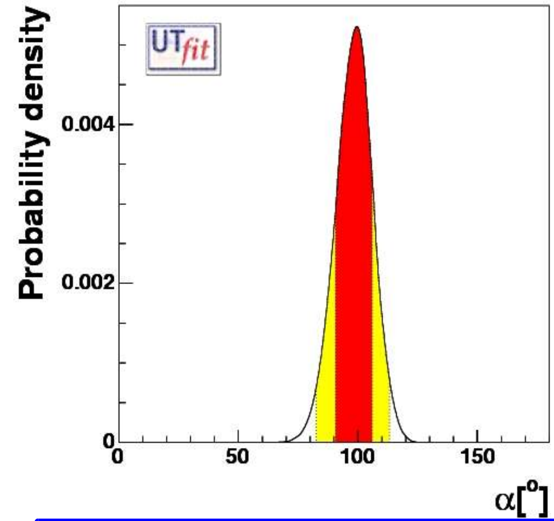
$\bar\rho = 0.214 \pm 0.047$
[0.112, 0.307] @ 95% Prob.

$\bar\eta = 0.343 \pm 0.028$
[0.289, 0.396] @ 95% Prob.

Indirect determinations:







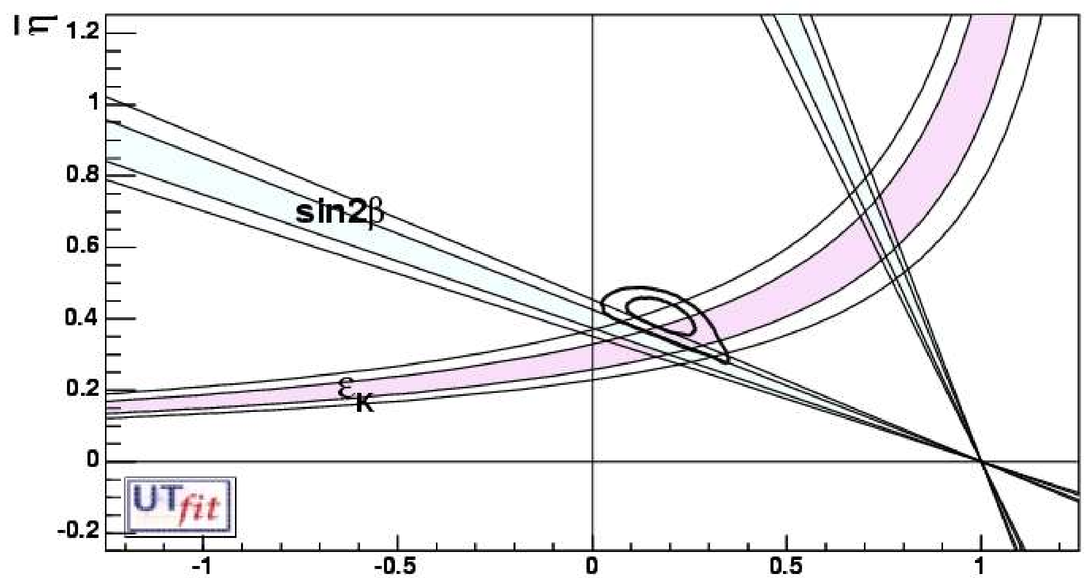
$\sin 2\beta = 0.734 \pm 0.024$
[0.685, 0.781] @ 95% Prob.

$\gamma = 57.9° \pm 7.4°$
[43.8, 73.5]° @ 95% Prob.

$\alpha = 98.2° \pm 7.7°$
[82.4, 113.0]° @ 95% Prob.

from experiment
$\sin 2\beta = 0.687 \pm 0.032$

from the only-side fit
$\sin 2\beta = 0.793 \pm 0.033$



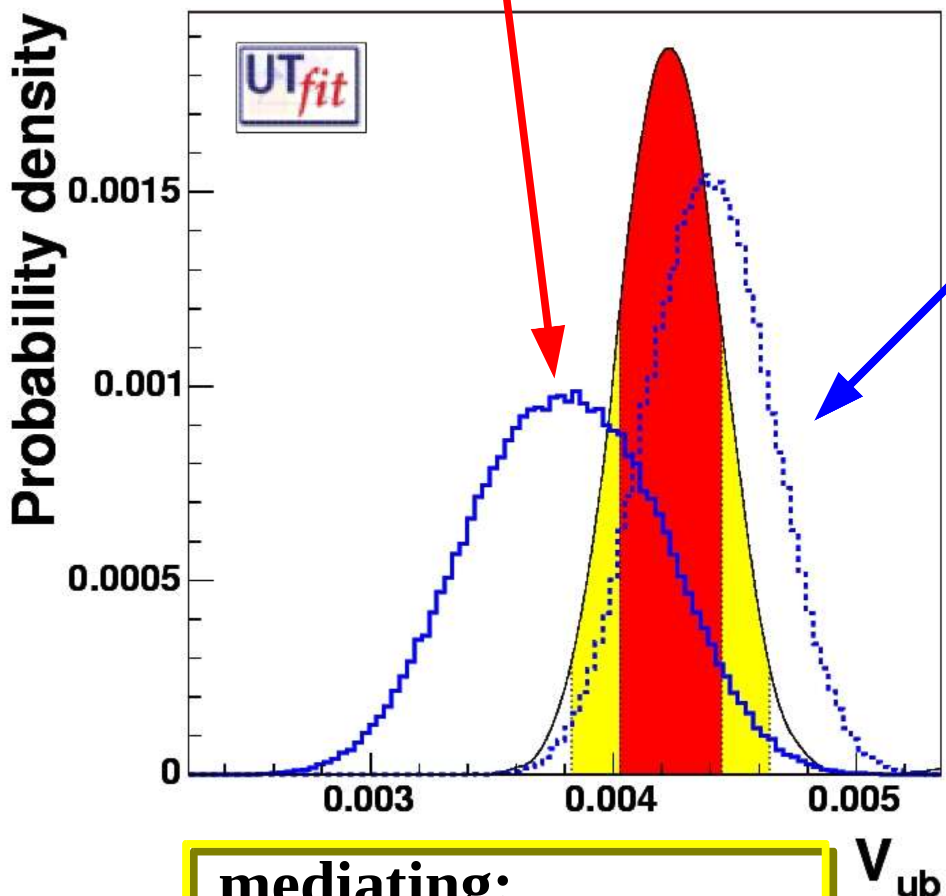
only side results included

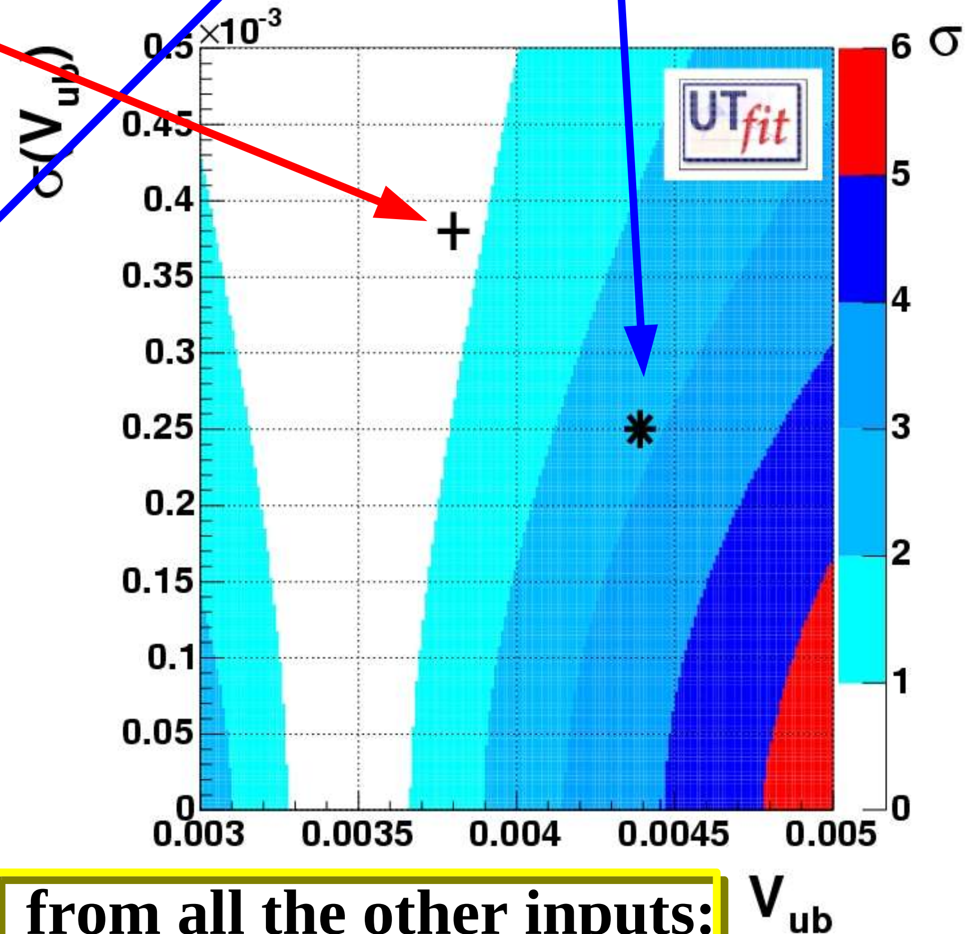
V_{ub}

exclusive value:
semileptonic BRs from HFAG
form factor (courtesy of V. Lubicz)
$V_{ub} = (3.80 \pm 0.27 \pm 0.47)\ 10^{-3}$

from quenched LQCD

inclusive value: from HFAG
$V_{ub} = (4.38 \pm 0.19 \pm 0.27)\ 10^{-3}$

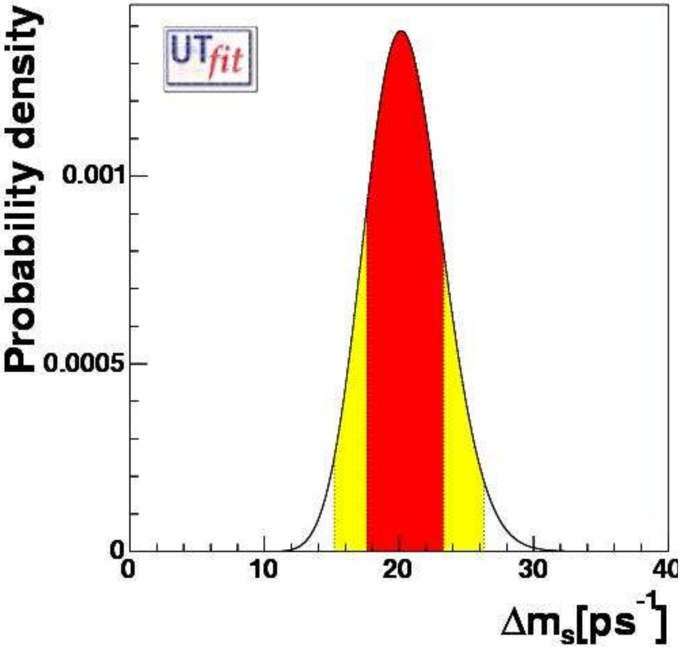




mediating:
$V_{ub} = (4.22 \pm 0.20)\ 10^{-3}$

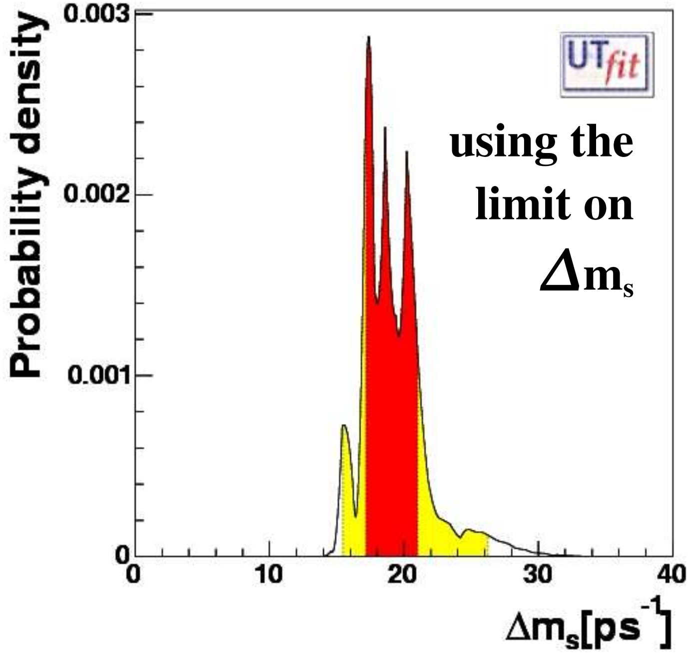
from all the other inputs:
$V_{ub} = (3.48 \pm 0.20)\ 10^{-3}$

Prediction on Δm_s and test on the SM

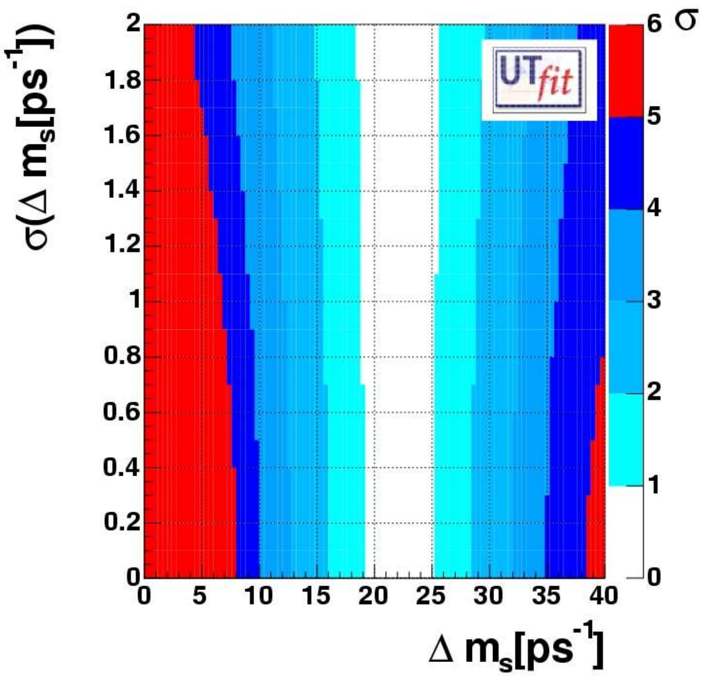


$\Delta m_s = 22.2 \pm 3.1\ ps^{-1}$
without the
experimental bound

red: 65%
yellow: 95%



$\Delta m_s = 19.1 \pm 2.0\ ps^{-1}$
with the
experimental bound



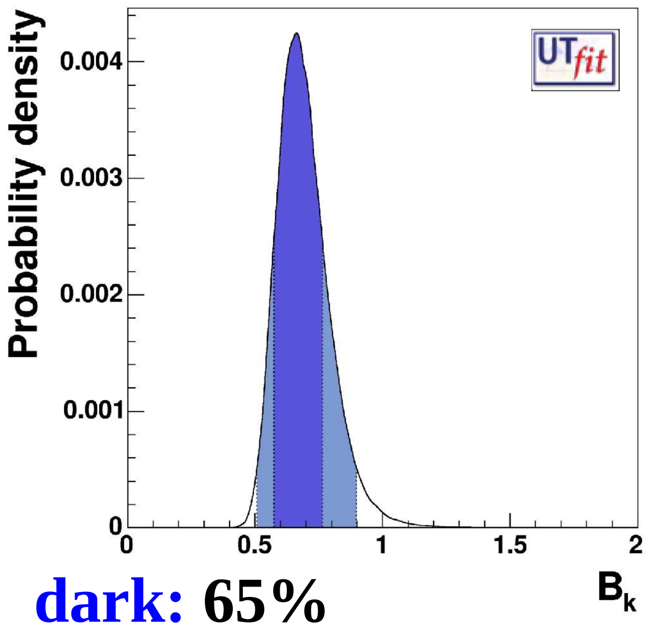
$\Delta m_s > 31\ ps^{-1}$
New Physics @ 3σ
[for $\sigma(\Delta m_s) \sim 1\ ps^{-1}$]

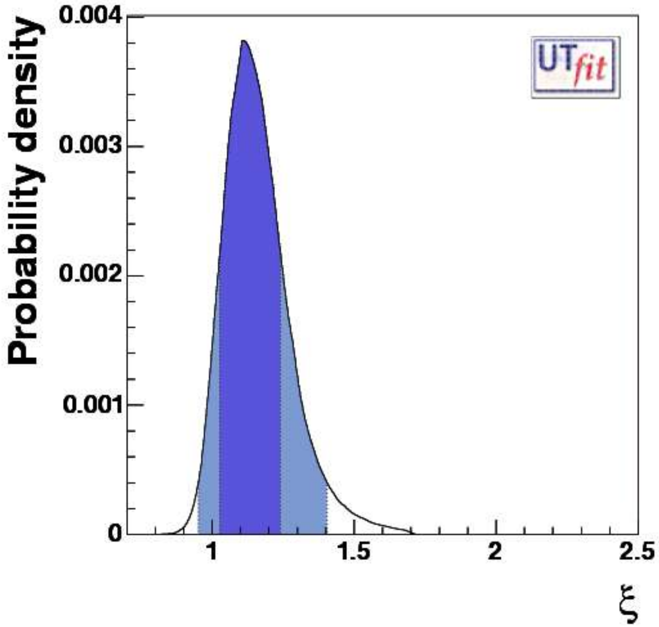
UTfit and LQCD predictions

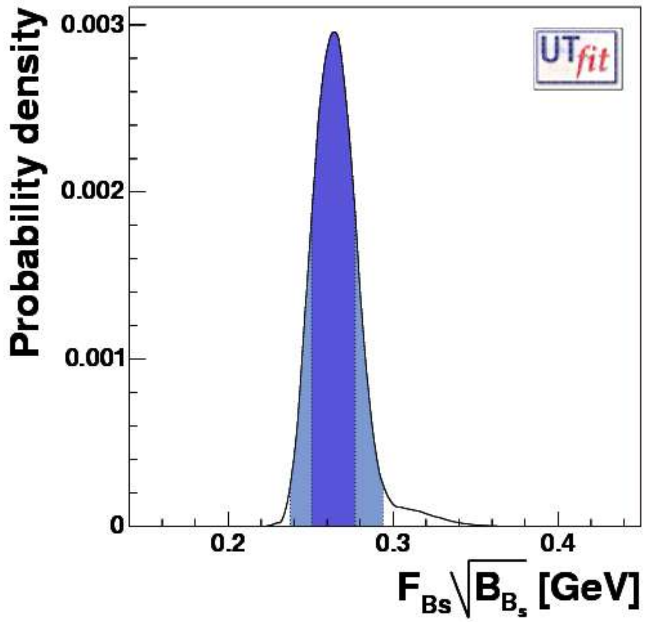
It is possible to obtain predictions on lattice QCD parameters employing all the other inputs

$B_K = 0.69 \pm 0.10$ UTfit

$B_K = 0.79 \pm 0.04 \pm 0.09$ LQCD







$f_{B_s}\sqrt{B_{B_s}} = 265 \pm 13$ UTfit

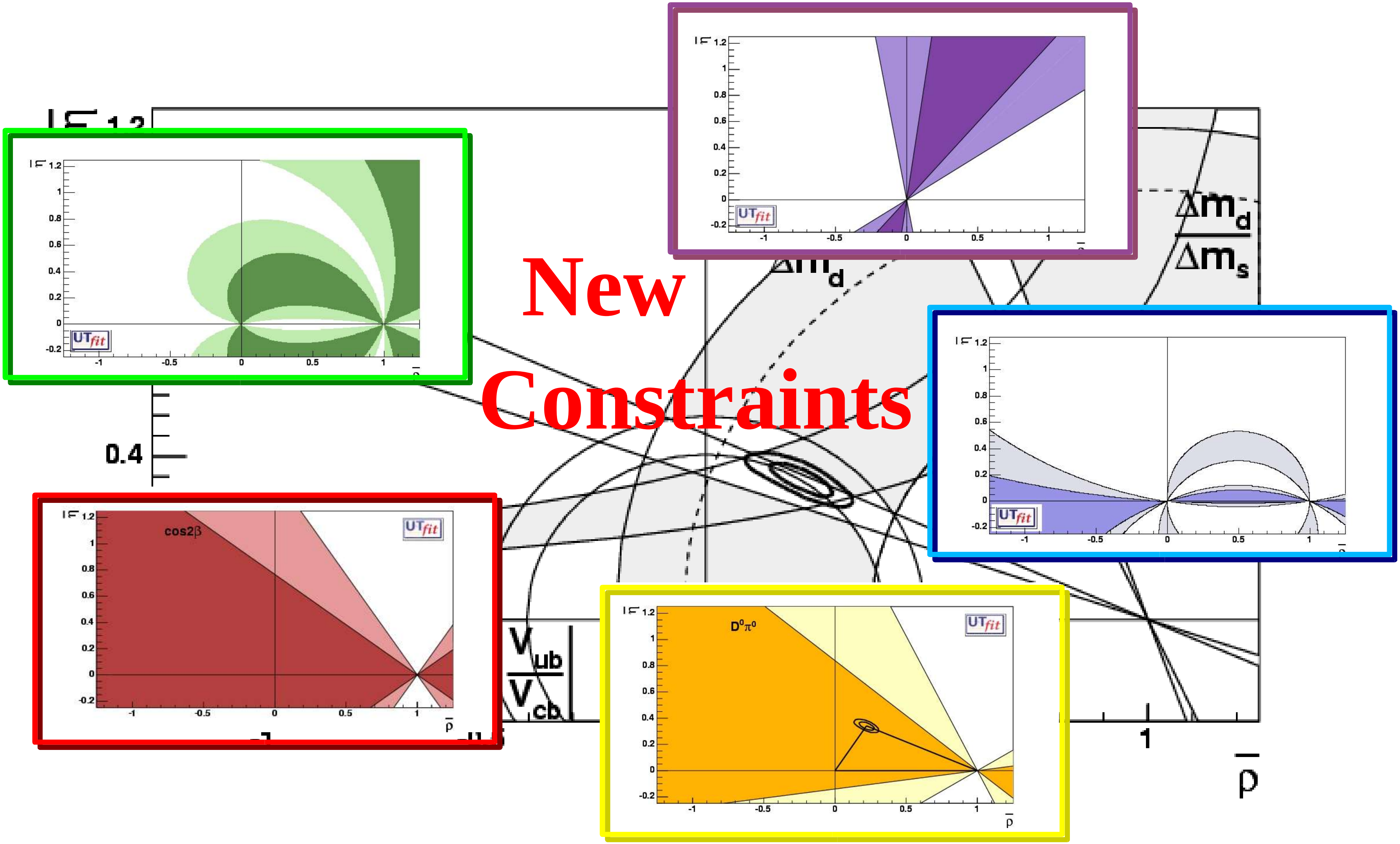
$f_{B_s}\sqrt{B_{B_s}} = 276 \pm 38$ LQCD

dark: 65%

light: 95%

$\xi = 1.15 \pm 0.11$ UTfit

$\xi = 1.24 \pm 0.04 \pm 0.06$ LQCD


New
Constraints
Δm_d
$\frac{\Delta m_d}{\Delta m_s}$
$\left|\frac{V_{ub}}{V_{cb}}\right|$
cos2β
$D^0\pi^0$
UTfit
$\bar{\eta}$
$\bar{\rho}$

α from isospin analysis: $\pi\pi$, $\rho\rho$, $\rho\pi$

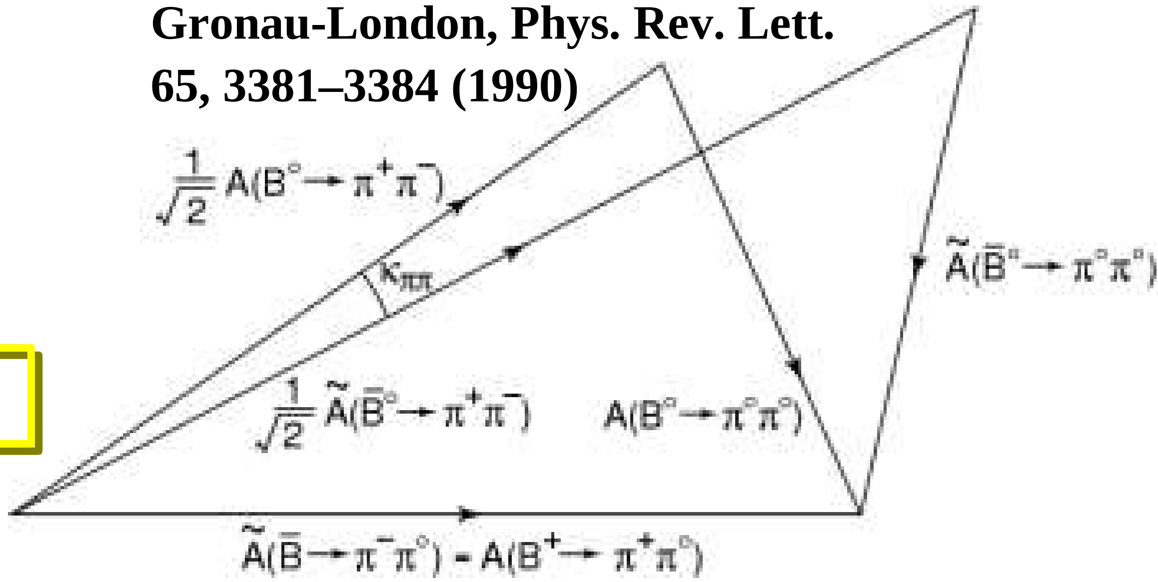
Starting from the SU(2) amplitudes ($\pi\pi$, $\rho\rho$):

$A^{+-} = -Te^{-i\alpha} + Pe^{i\delta_P}$

$A^{+0} = -1/\sqrt{2}\, e^{-i\alpha} (T + T_C\, e^{i\delta_C})$

$A^{00} = -1/\sqrt{2}\, (T_C\, e^{i\delta_C}\, e^{-i\alpha} + Pe^{i\delta_P})$

Gronau-London, Phys. Rev. Lett. 65, 3381–3384 (1990)



unknowns: T, P, T_C, δ_P, δ_{T_C}, α

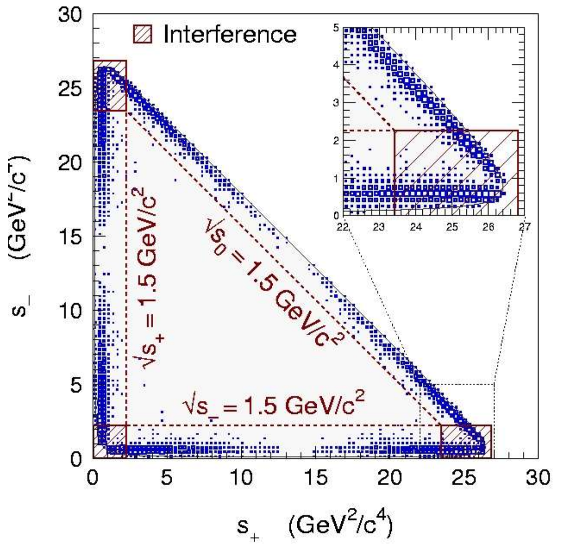
observable: 3x BR, C_{+-}, S_{+-}, C_{00}

Similar analysis for $(\rho\pi)^0$ on the Dalitz plane

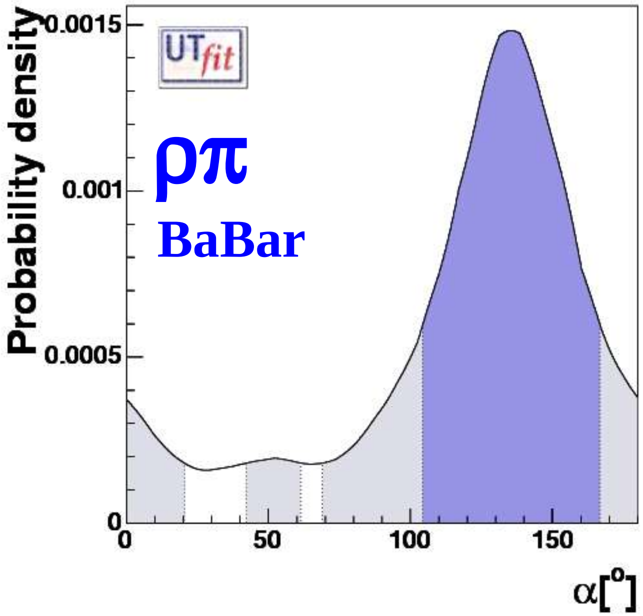
$A^k = T^k e^{-i\alpha} + P^k$

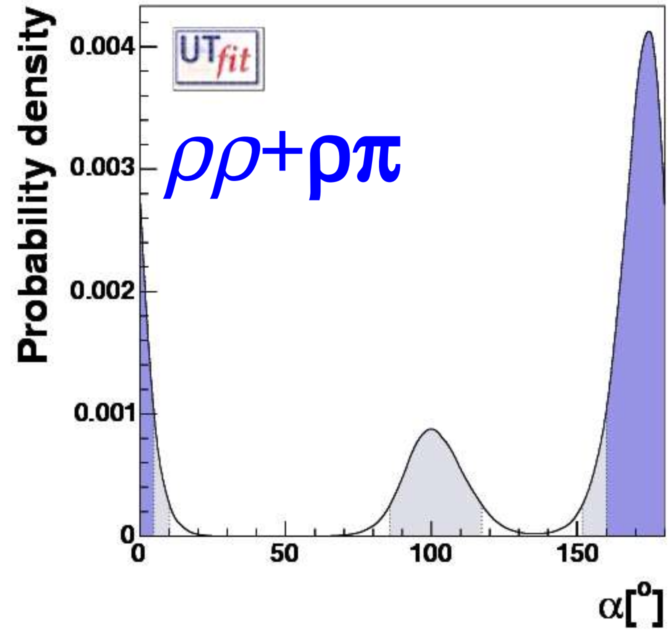
$\bar{A}^k = T^{\bar{k}} e^{i\alpha} + P^{\bar{k}}$

with k=+- for $\rho^+\pi^-$, -+ for $\rho^-\pi^+$, e 00 for $\rho^0\pi^0$

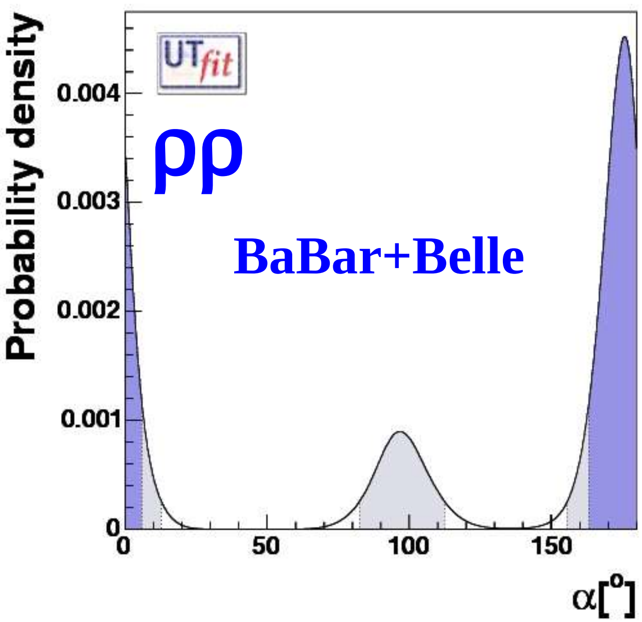


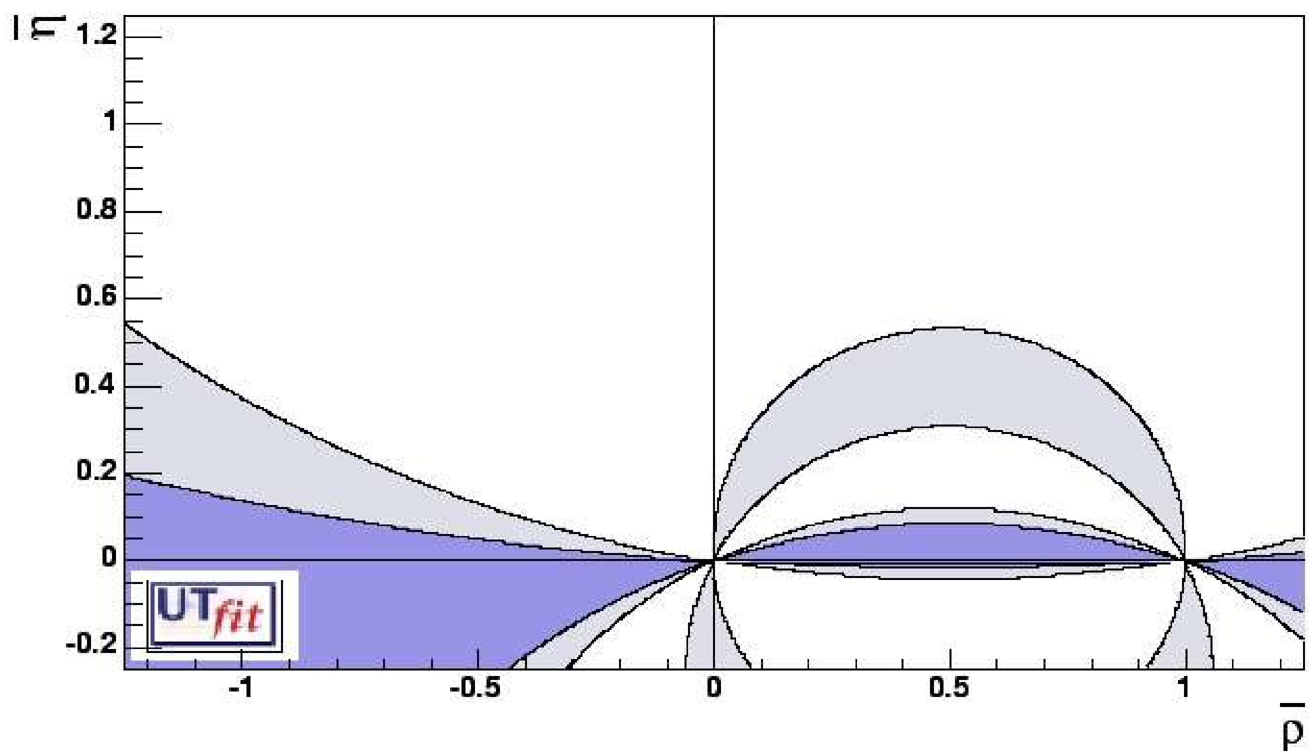
α from isospin analysis (II): $\rho\rho$, $\rho\pi$





α = [86, 107]º
U
[152, 90]º
@ 95% Prob.

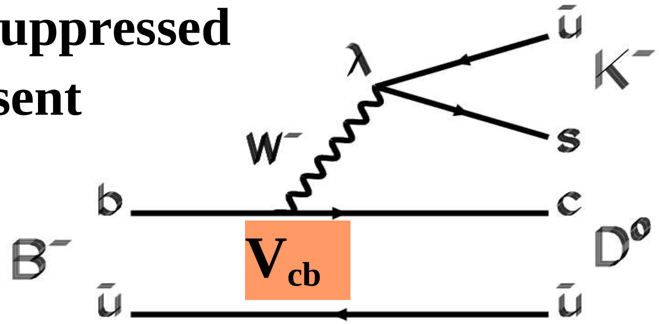




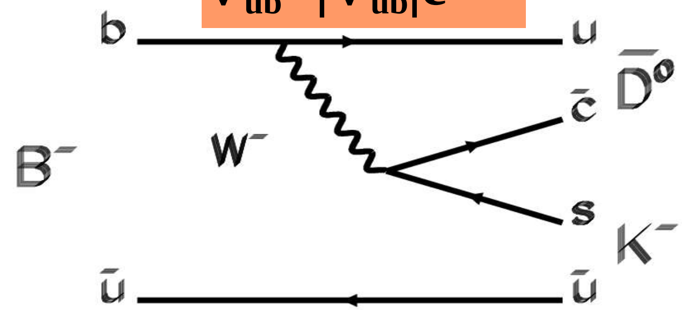
γ: from B → D(*)K(*) decays

also the color-suppressed diagram is present

r_B = ratio of amplitudes



$V_{ub}=|V_{ub}|e^{-i\gamma}$



δ_B = strong phase diff.

$$A(B^- \to D^0 K^-) = A_B \quad A(B^- \to \bar{D}^0 K^-) = A_B r_B e^{i(\delta_B - \gamma)}$$
$$A(B^+ \to \bar{D}^0 K^+) = A_B \quad A(B^+ \to D^0 K^+) = A_B r_B e^{i(\delta_B + \gamma)}$$

- ADS(Atwood,Dunietz,Soni) method: B^0 and $\bar{B}^0$ into the same final state

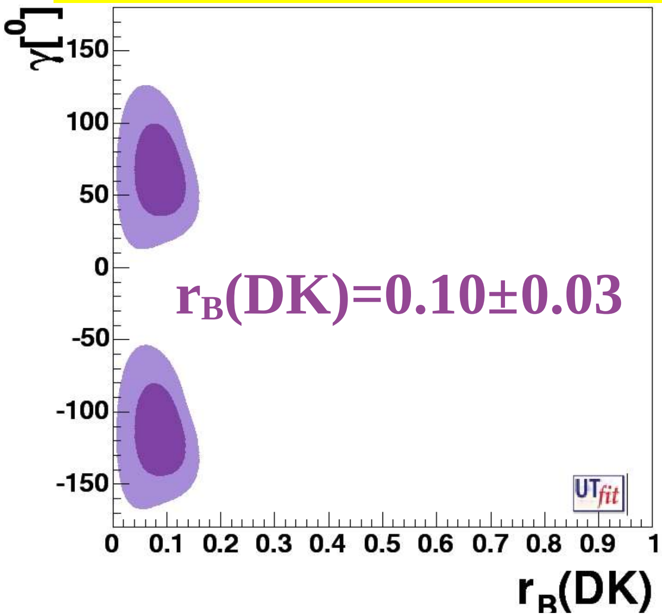
$$R_{ADS} = r_B^2 + r_{DCS}^2 + 2 r_B r_{DCS} \cos\gamma \cos(\delta_B + \delta_D)$$

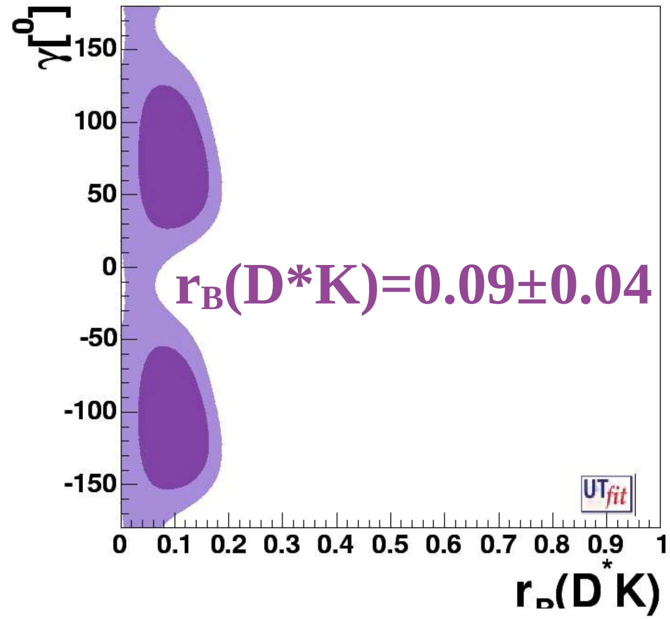
- GLW(Gronau, Londow,Wyler) method: looks for the CP eigenstates of the D $D^{(*)0}_{CP}$

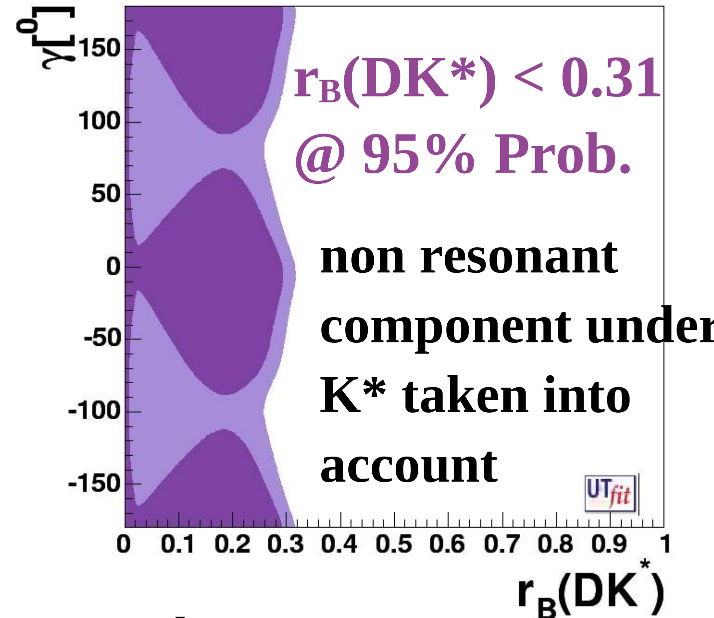
$$R_{CP\pm} = 1 + r_B^2 \pm 2 r_B \cos\gamma \cos\delta_B \quad A_{CP\pm} = \frac{\pm 2 r_B \sin\gamma \sin\delta_B}{1 + r_B^2 \pm 2 r_B \cos\gamma \cos\delta_B}$$

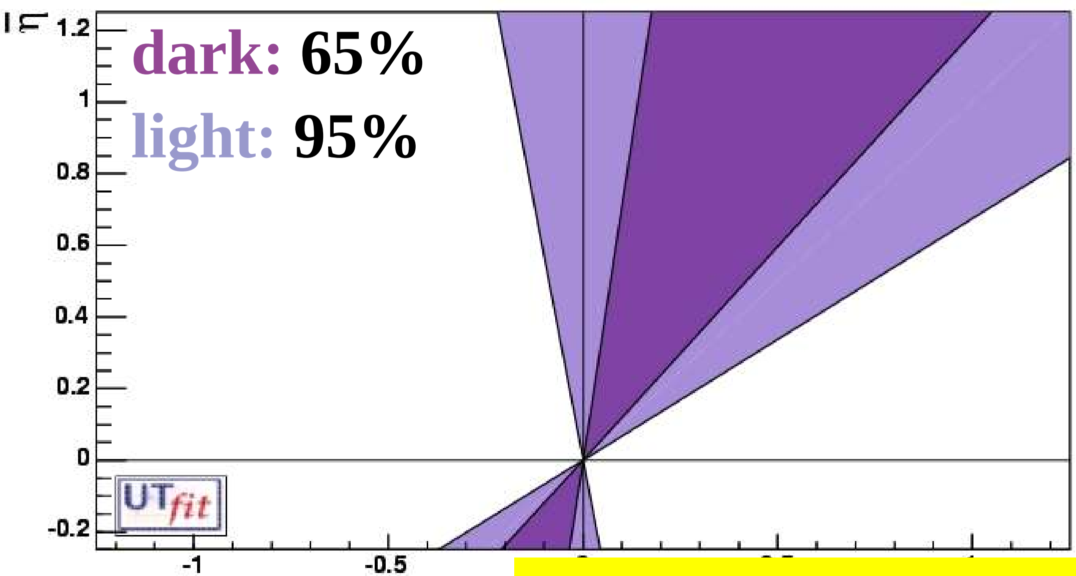
- D^0 Dalitz plot analysis with $B^- \to D^{(*)0}[K_S \pi^+ \pi^-] K^-$ decays

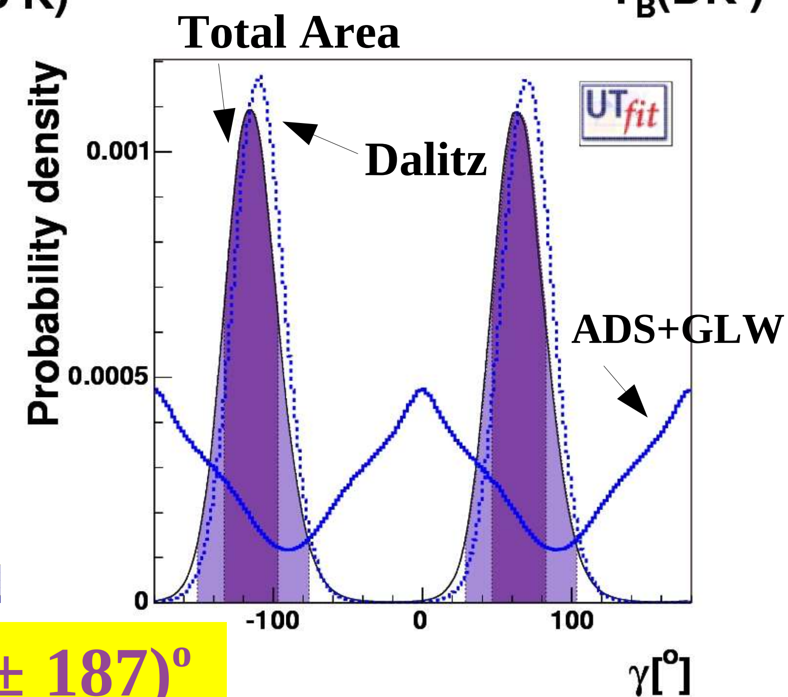
γ: from $B^{\pm} \rightarrow D(*)K(*)$ decays (II)







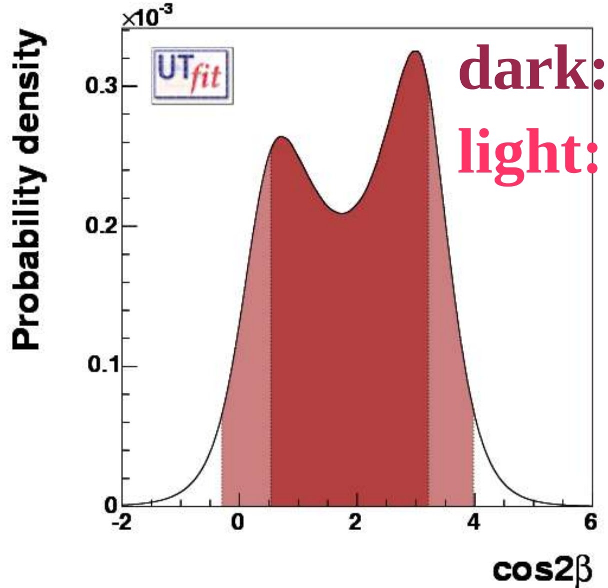


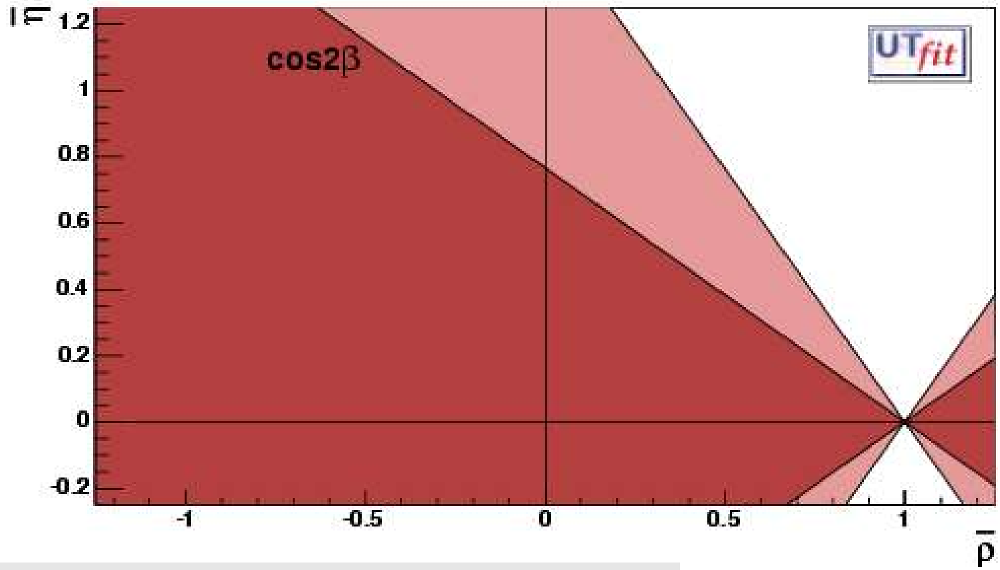


$\gamma = (66 \pm 17)^{o}$ U $(-114 \pm 187)^{o}$

$\cos 2\beta$ from $B \to J/\psi K^{*0}$

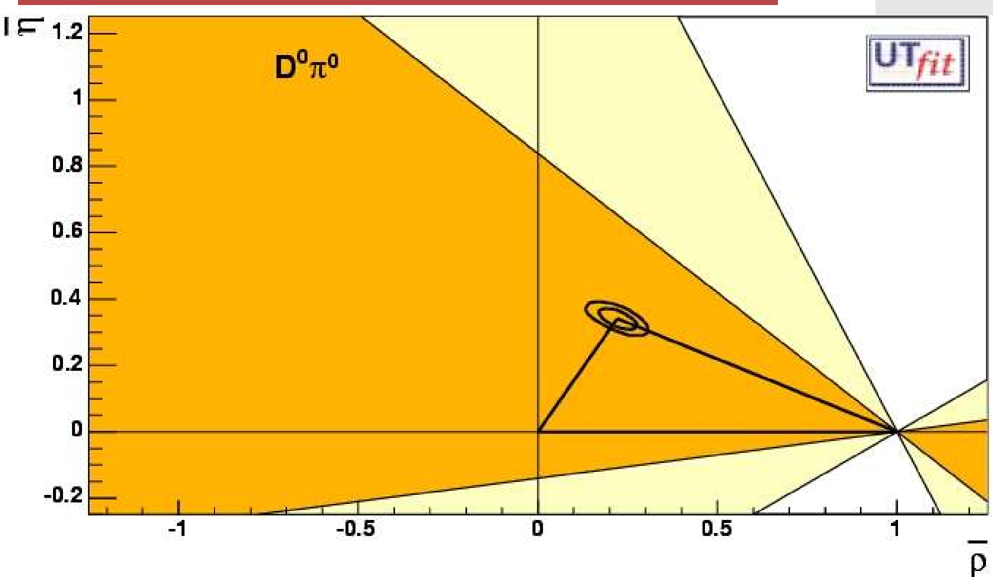
Skeptical combination
$\cos 2\beta = 1.9 \pm 1.3$
> 0 @ 87% Prob.

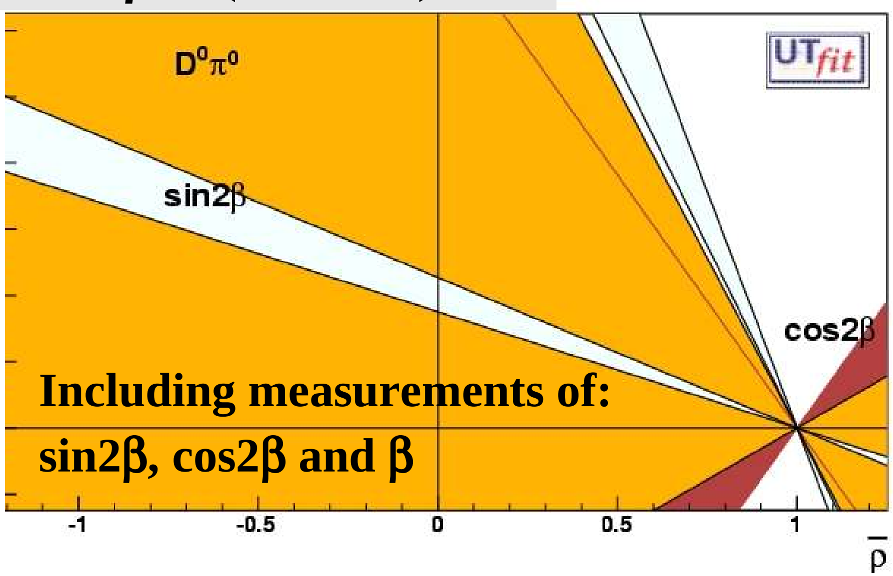




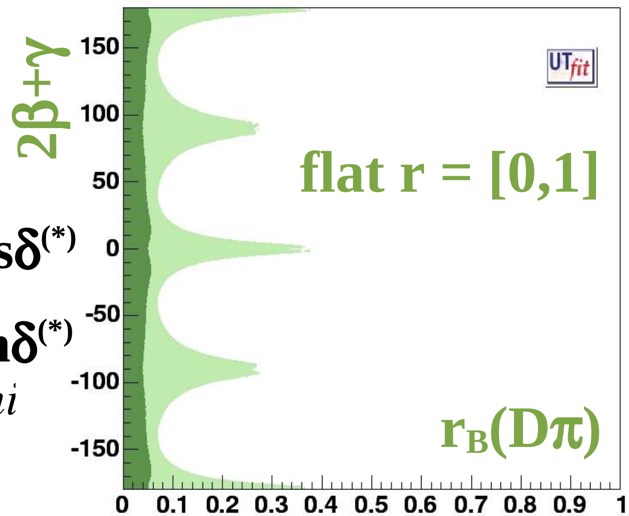
β from $B^0 \to D^0\pi^0$

Dalitz plot analysis: $\beta \to \beta+\pi$
Belle result: $\beta = (16 \pm 24)^o$





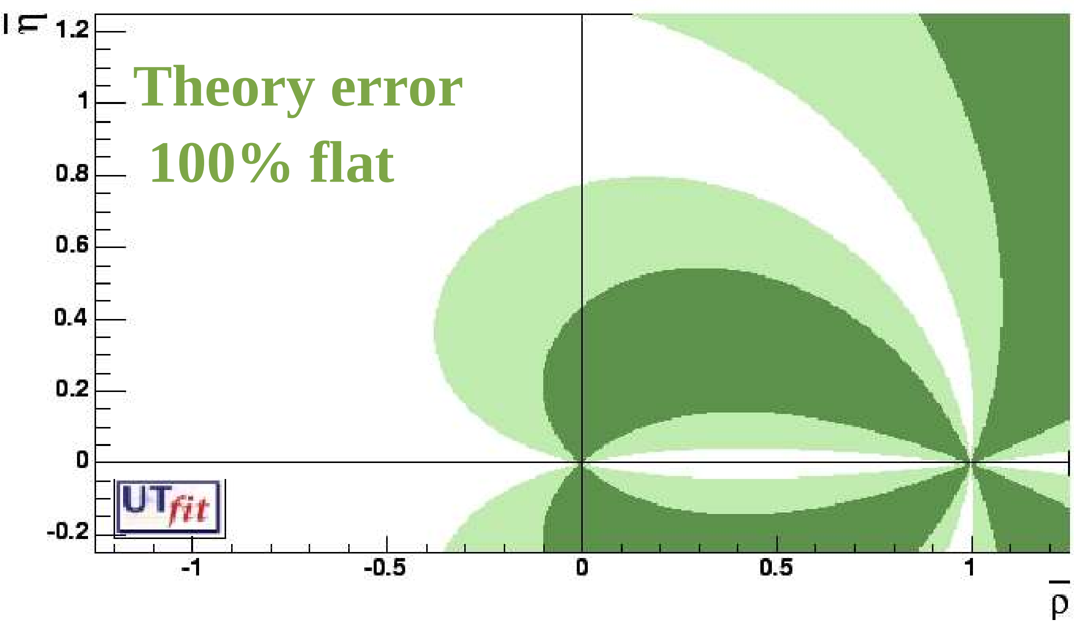
$2\beta+\gamma$ from $B \to D^{(*)}\pi(\rho)$



$a^{(*)} = 2r^{(*)}\sin(2\beta+\gamma)\cos\delta^{(*)}$

$c^{(*)} = 2r^{(*)}\cos(2\beta+\gamma)\sin\delta^{(*)}$

(leptoni



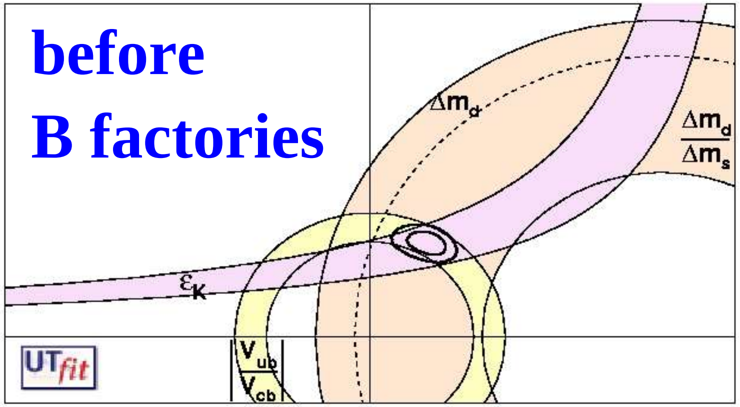
- Interference b→u vs b→c like in DK decays
- Open system: 2 observables for $2\beta+\gamma$, r and δ
- Only assuming r we can extract $2\beta+\gamma$

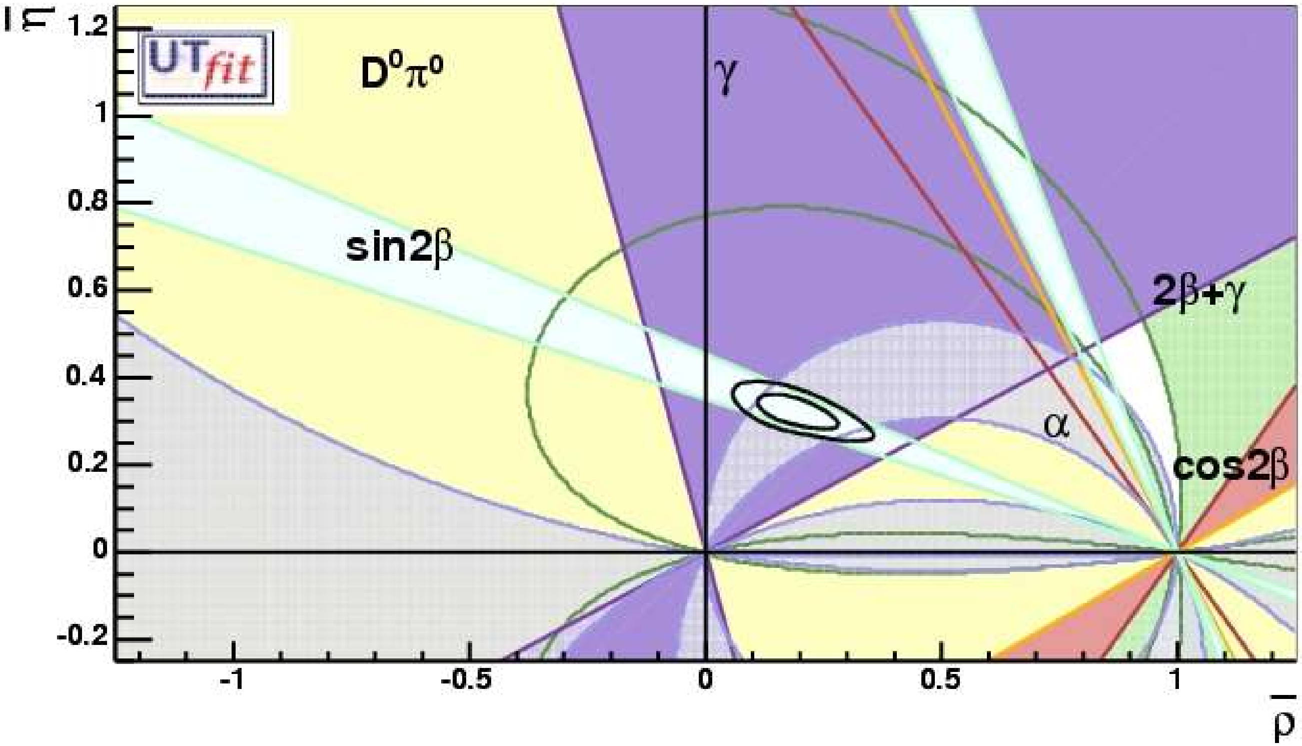
- Extraction of r from $B \to D_s\pi$
- Theory error ~100% flat to take into account SU(3) breaking and annihilations in B to Dπ

See D. Pirjol, talk at Beauty 2005

Angles only:

$\sin 2\beta + \cos 2\beta + \beta + \gamma + \alpha + 2\beta+\gamma$





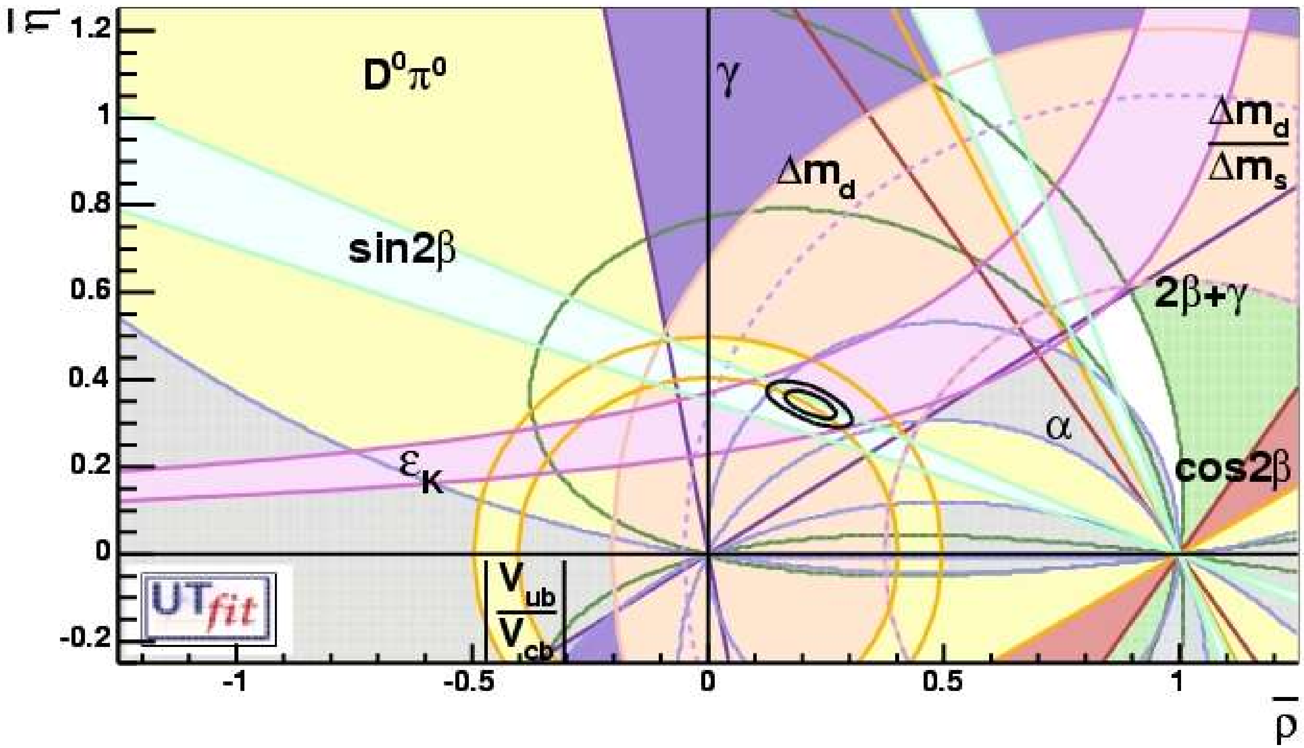
Precision comparable to the analysis in the pre-B-factory era

$\bar{\rho} = 0.193 \pm 0.057$
[0.083, 0.321] @ 95% Prob.

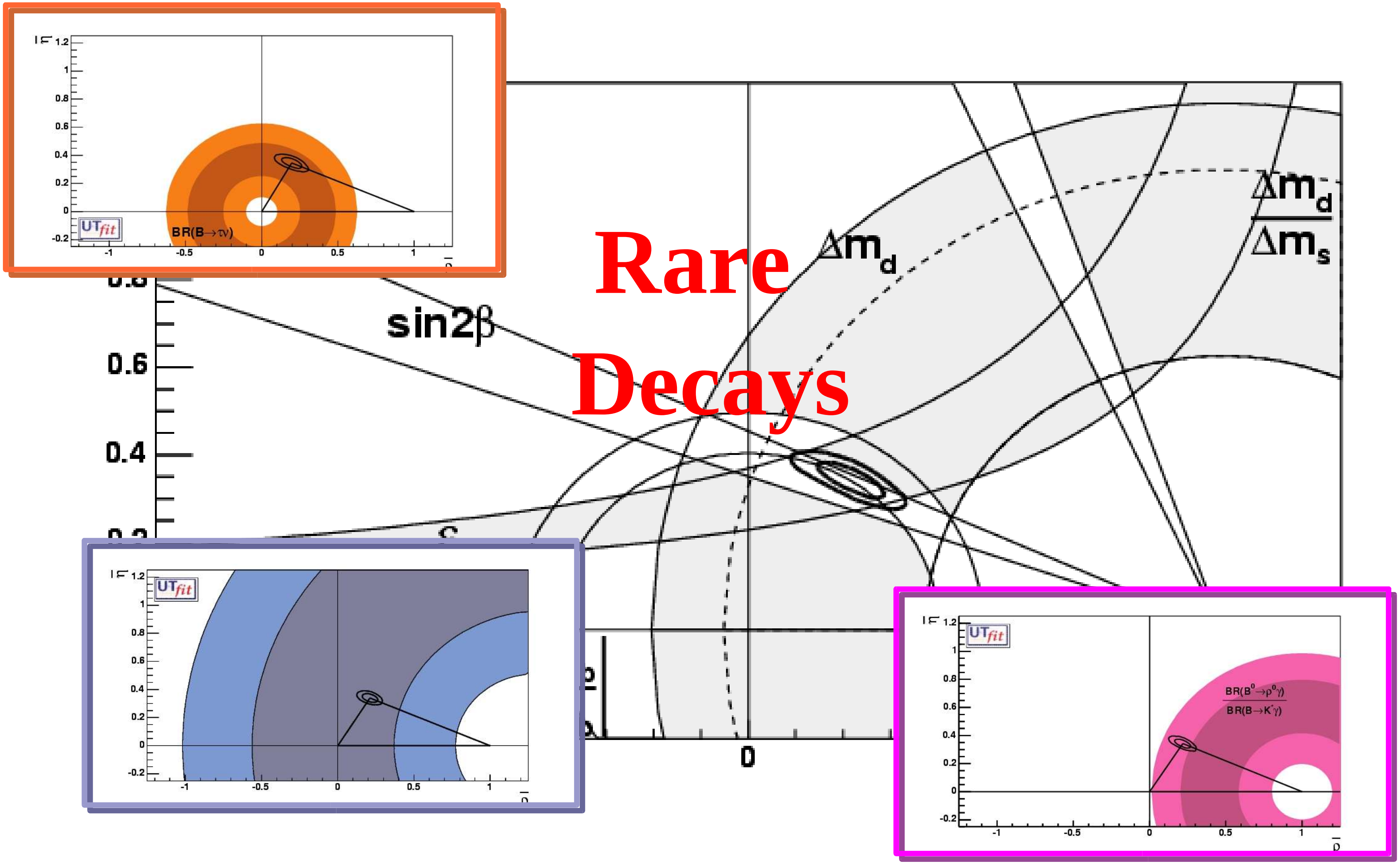
$\bar{\eta} = 0.321 \pm 0.027$
[0.266, 0.376] @ 95% Prob.

Including all the constraints

standard analysis + cos2β + β + γ + α + 2β+γ



$\bar{\rho} = 0.216 \pm 0.036$	$\bar{\eta} = 0.342 \pm 0.022$
[0.143, 0.288] @ 95% Prob.	[0.300, 0.385] @ 95% Prob.


Rare
Decays
Δm_d
$\frac{\Delta m_d}{\Delta m_s}$
sin2β
0.6
0.4
0
UTfit
BR(B→τν)
$\overline{\eta}$
$\overline{\rho}$
$\frac{BR(B^0 \to \rho^0\gamma)}{BR(B \to K^*\gamma)}$

$K^\pm \to \pi^\pm\nu\bar\nu$

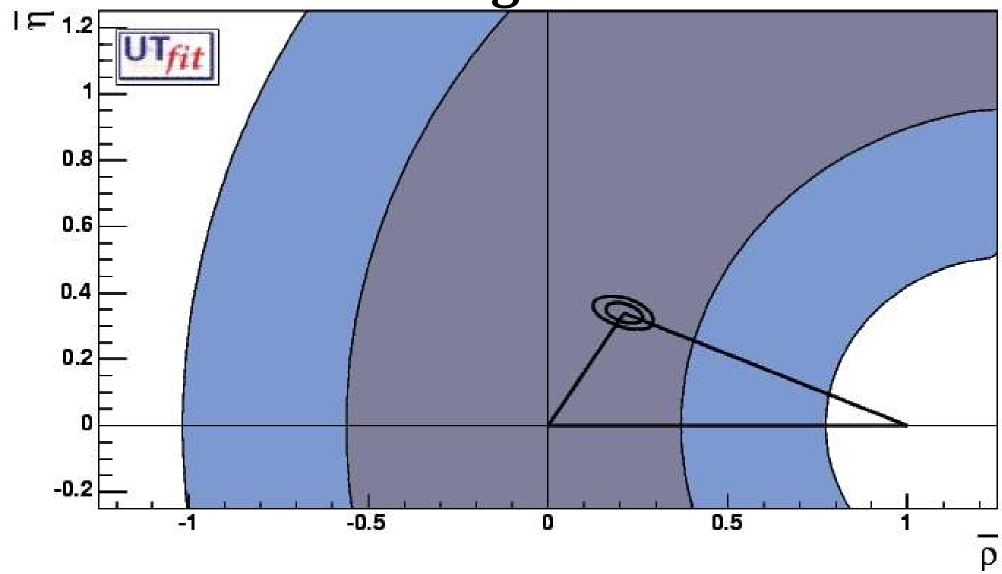
$$\underbrace{(\sigma\bar{\eta})^2 + (\bar{\rho}-\bar{\rho}_0)^2}_{\text{ellipse centered in } (\rho^0,\,0)} = \frac{\sigma BR(K^+ \to \pi^+\nu\bar{\nu})}{\bar{\kappa}_+ |V_{cb}|^4 X^2(x_t)}$$

D'Ambrosio, Isidori
hep-ph/0112135

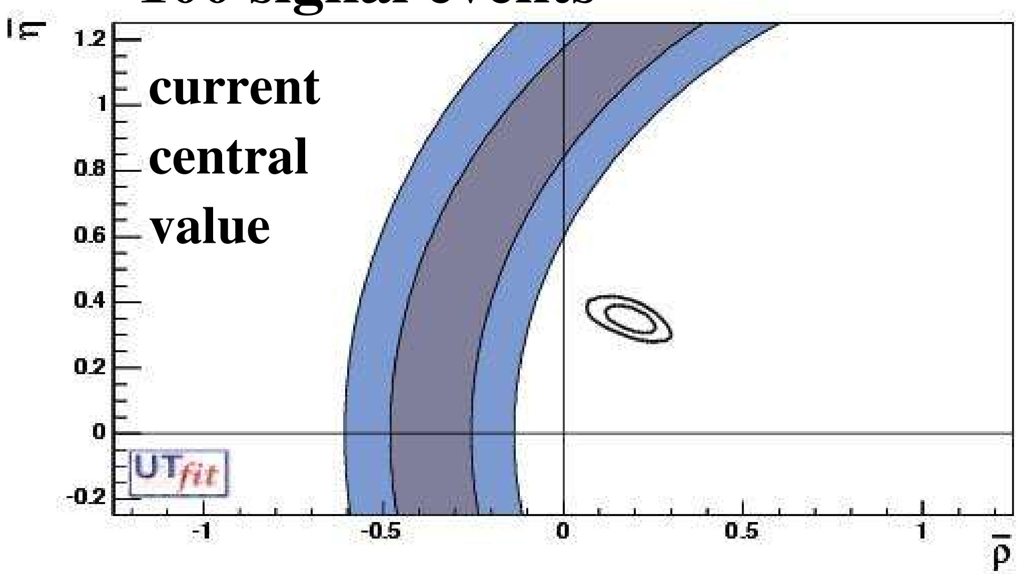
latest result from E949:

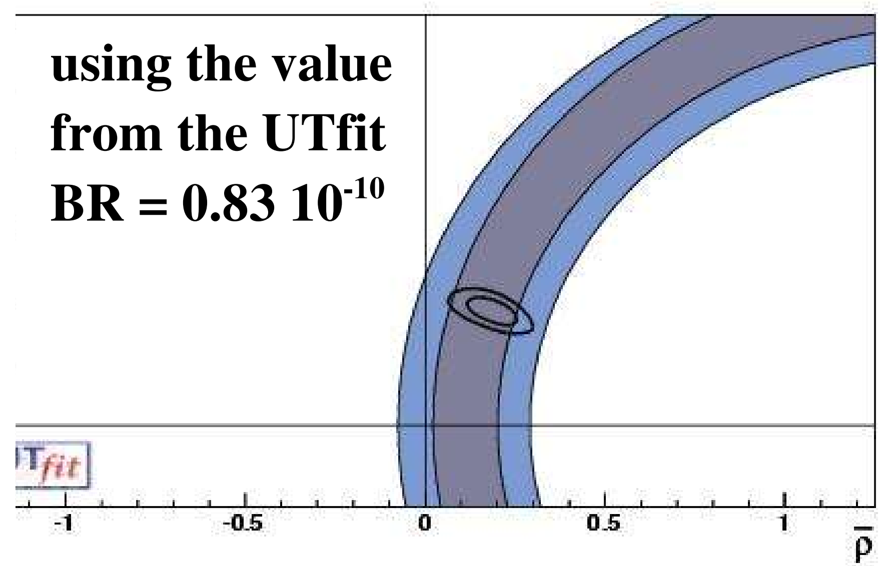
$BR(K^\pm \to \pi^\pm\nu\bar\nu) = 1.47^{+1.30}_{-0.89}\ 10^{-10}$

with 3 signal events



with the hypothesis of ~100 signal events





BR(B → ργ) / BR(B → K*γ)

$$R = c_\rho^2 \frac{r_m}{\xi^2} \frac{|a_7^c(\rho\gamma)|^2}{|a_7^c(K^*\gamma)|^2} \frac{|V_{td}|^2}{|V_{ts}|^2} (1+\Delta R)$$

In case of penguin dominance, R = BR(B → ρ/ωγ)/BR(B → K*γ) can be used to extract $|V_{td}/V_{ts}|$, adding information wrt $\Delta m_d / \Delta m_s$.

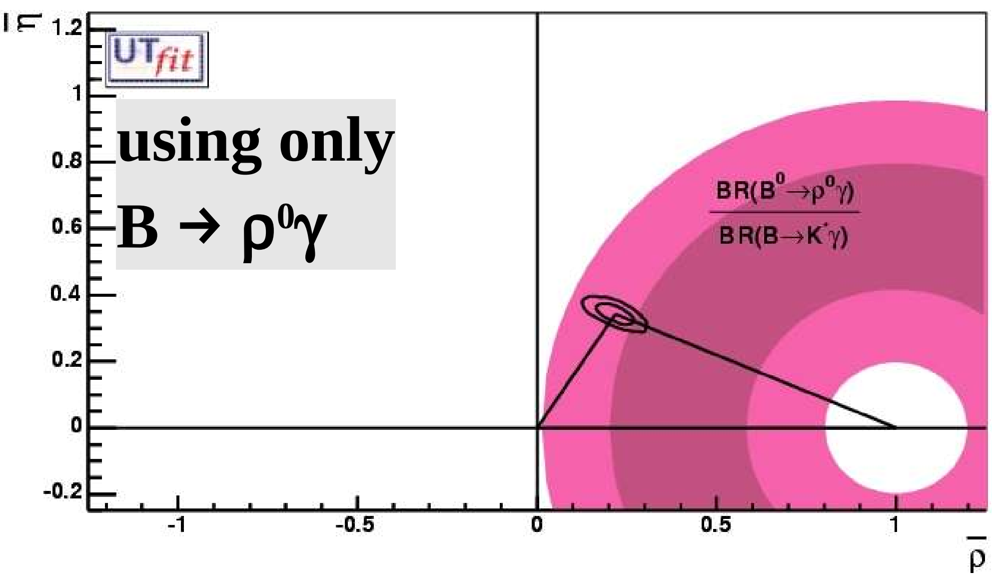
caveat: * SU(3) breaking effect

$\Delta R \sim O(\Lambda_{QCD}/m_b)$

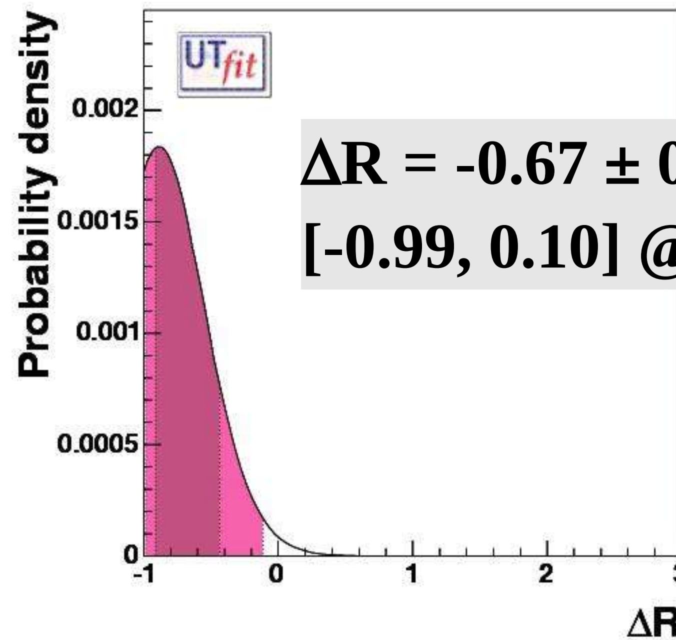
* annihilation in B to ρ/ω γ not in B to K*γ associated to a different CKM factor ($\sim V_{ub}^* V_{ud}$)

QCD factorisation

$|V_{td}/V_{ts}|$ = 0.10 ± 0.45
[0.02,0.18] @ 95% Prob.



Using the $|V_{td}/V_{ts}|$ value from the SM, we can extract ΔR.



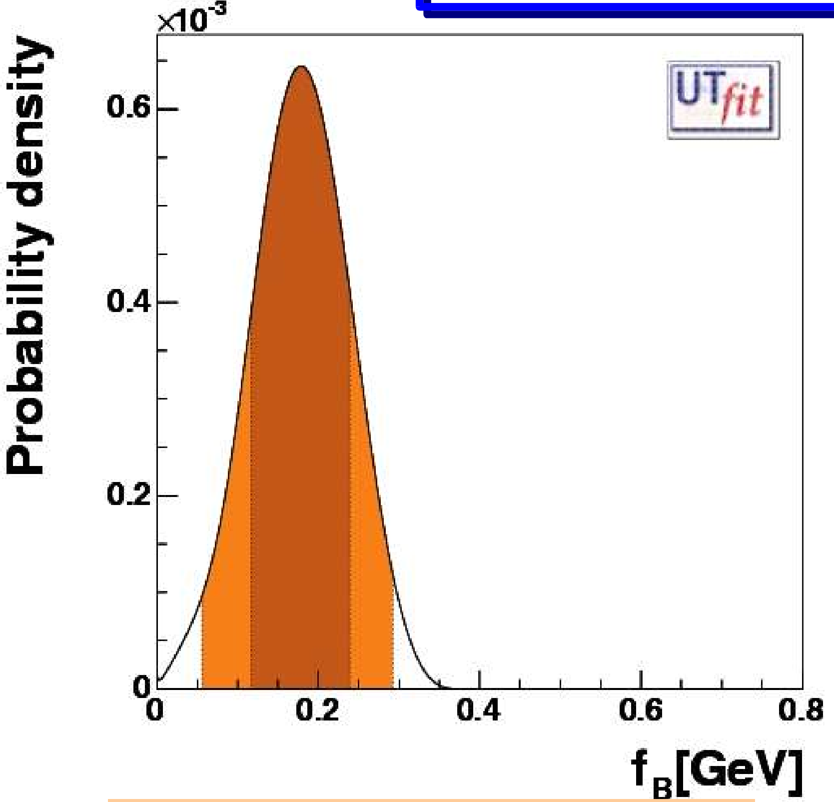
ΔR = -0.67 ± 0.24
[-0.99, 0.10] @ 95%

we use the likelihoods from BaBar and Belle

$B \to \tau\nu$

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

$< 1.8\ 10^{-4}$ @ 90% CL



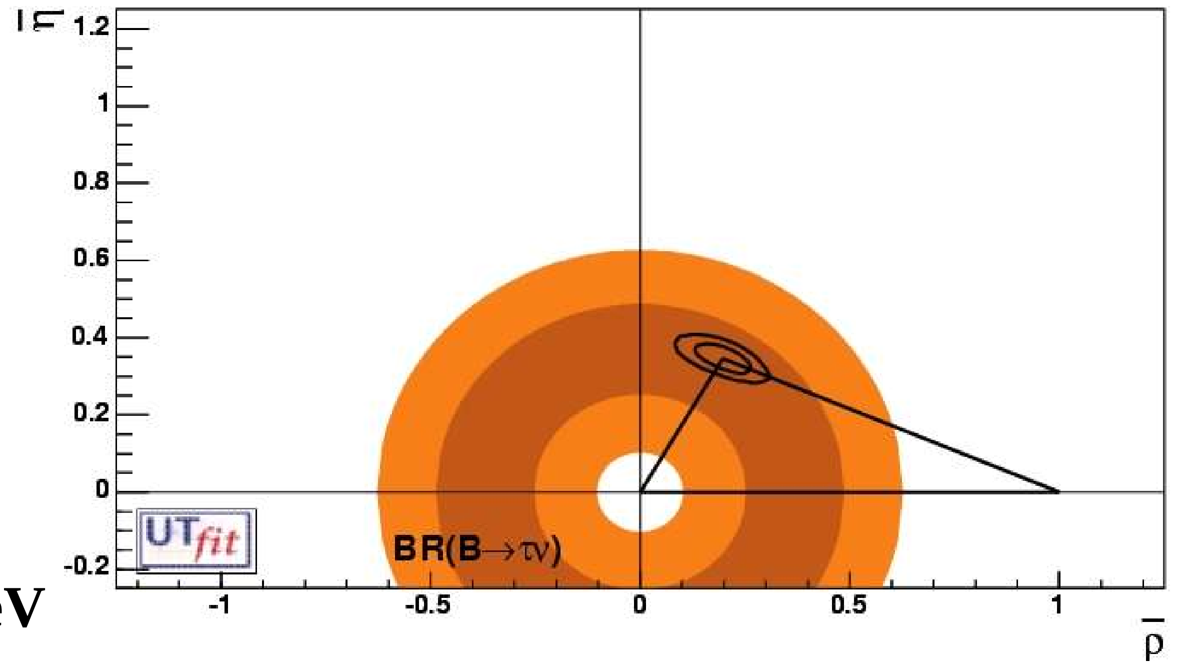
$f_{Bd} = 0.178 \pm 0.062$ GeV

$f_{Bd} = 0.192 \pm 0.026 \pm 0.009$ GeV from lattice QCD

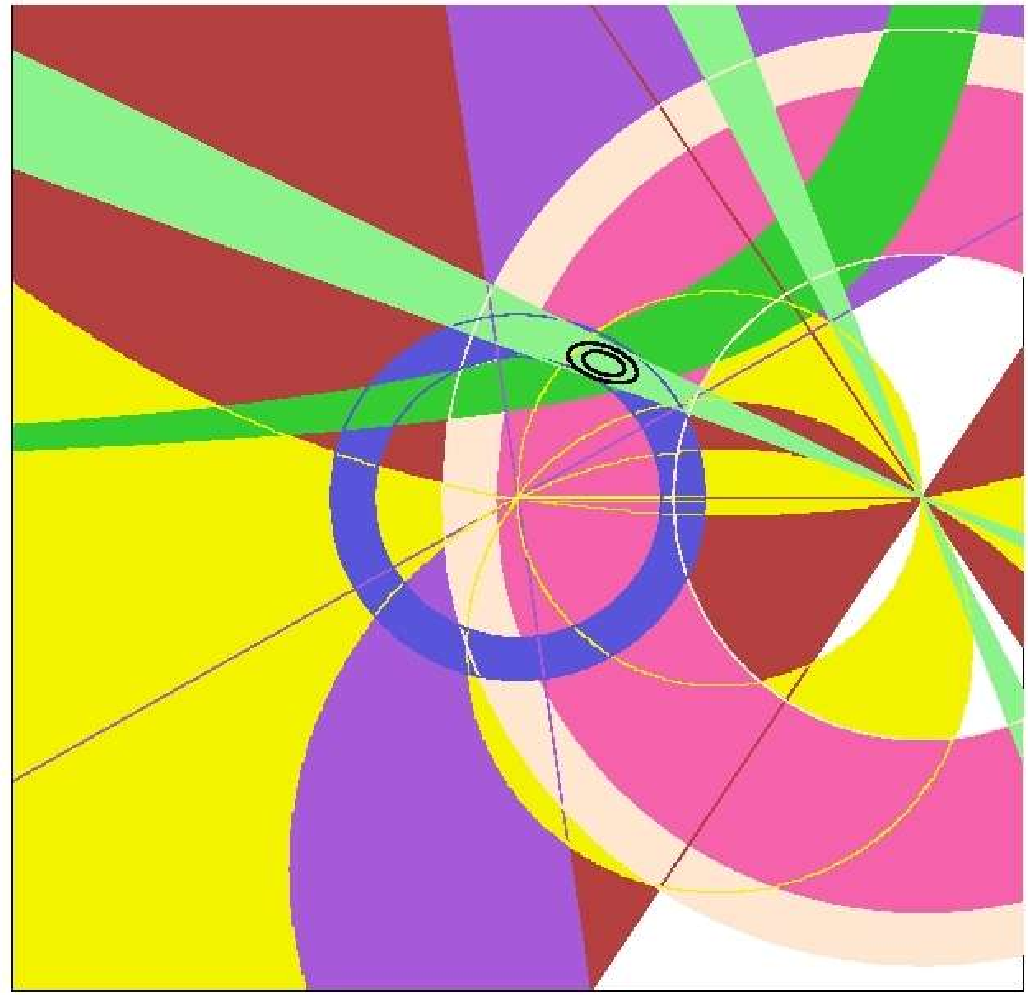
Assuming f_B :

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

R_b **= 0.37 ± 0.13**



We thank: A. Bevan, T. Browder, C. Campagnari, G. Cavoto, N. Danielson, R. Faccini, F. Ferroni, P. Gambino, T. Gershon, K. Ikado, M. Legendre, O. Long, F. Martinez, L. Roos, A. Poulenkov, M. Rama, Y. Sakai, M-H. Schune, W. Verkerke, C. Voena, A. Weiler, M.Zito. G. Isidori and D. Jaffe for the rare decays. D. Paus for Δm_s.



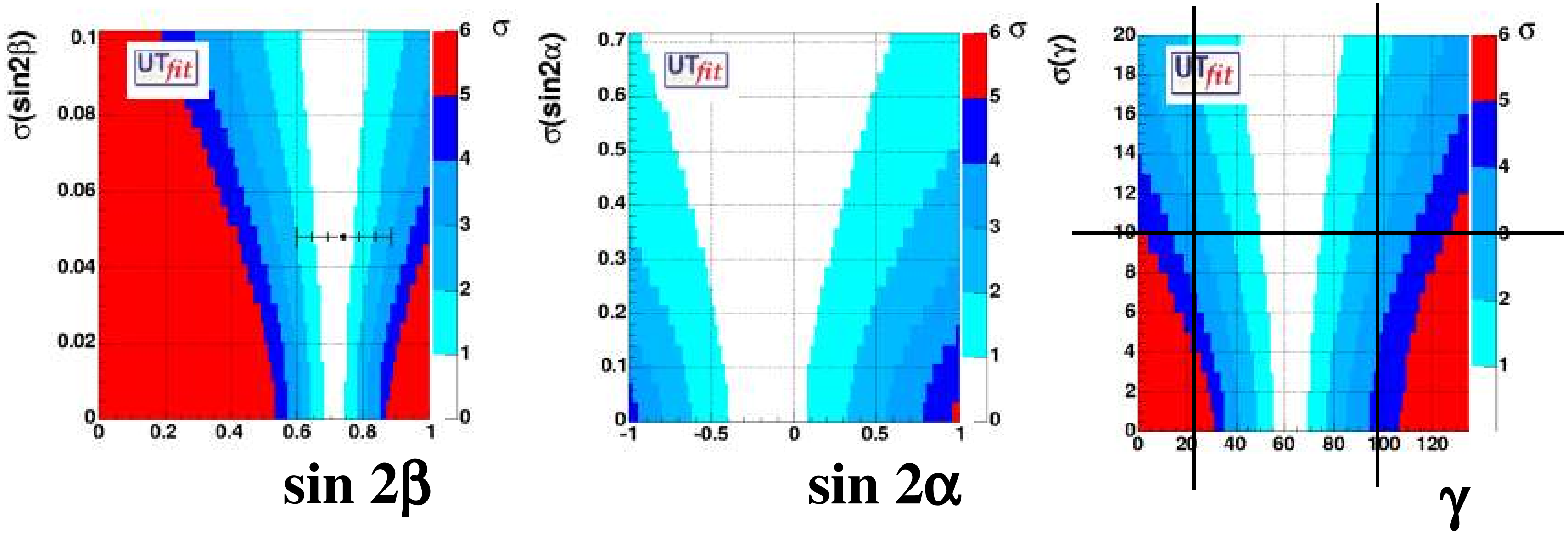
www.utfit.org

Back up slides

Compatibility plots:

red: 5σ exclusion zone

γ > 100°, γ < 25° } new physics @ 3σ level

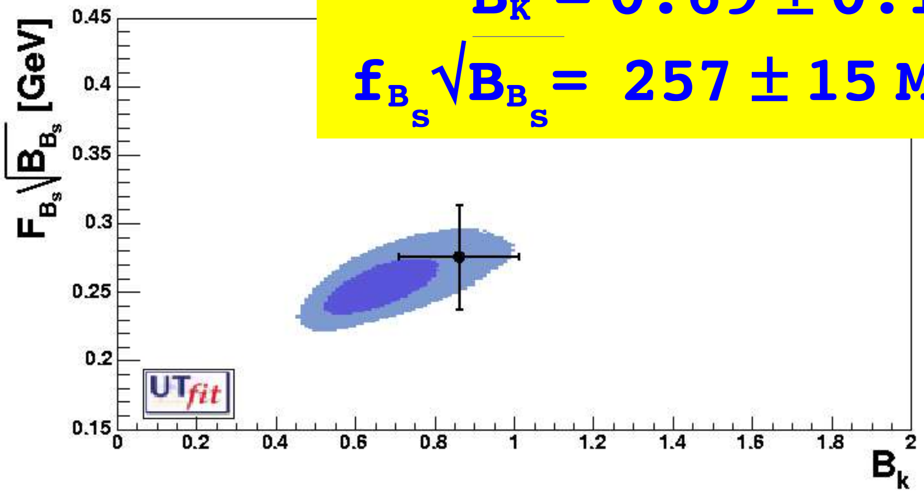


comparison between the indirect determination and a (hypothetical) direct experimental determination

UTfit and LQCD predictions (II)

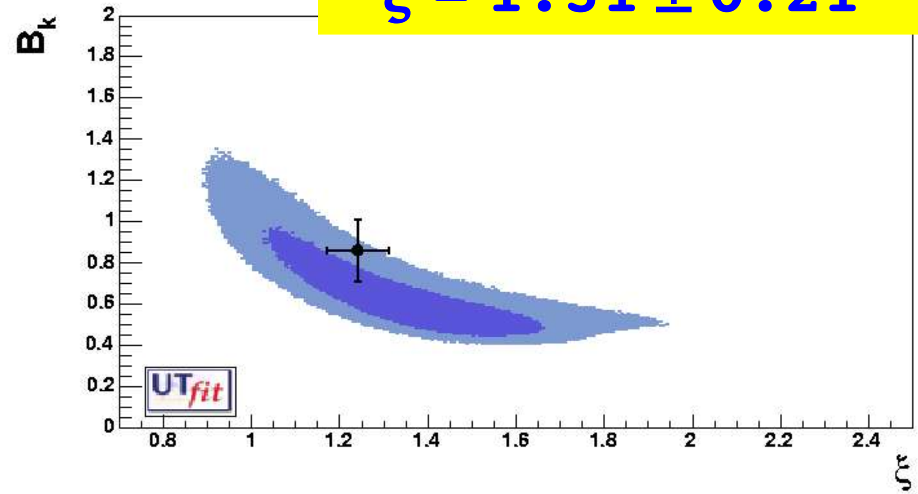
$B_K = 0.69 \pm 0.10$

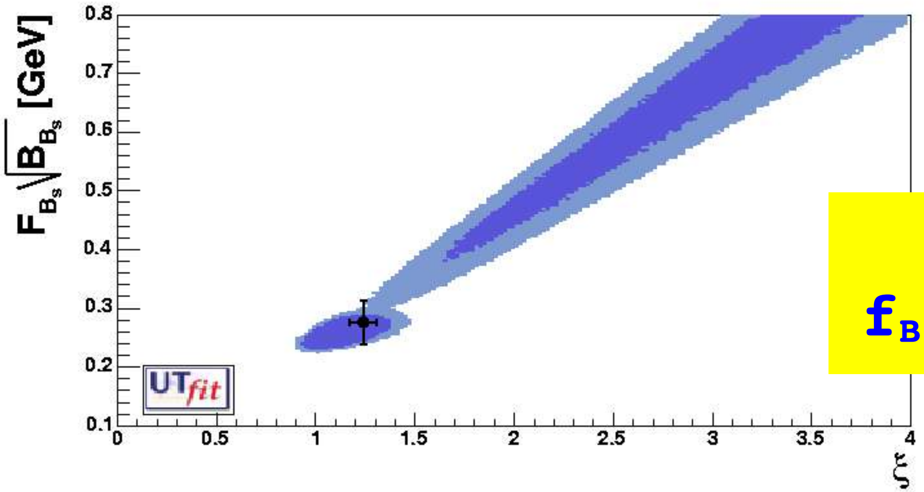
$f_{B_s}\sqrt{B_{B_s}} = 257 \pm 15$ MeV



$B_K = 0.68 \pm 0.18$

$\xi = 1.31 \pm 0.21$





$\xi > 0.9$

$f_{B_s}\sqrt{B_{B_s}} > 200$ MeV

dark: 65%

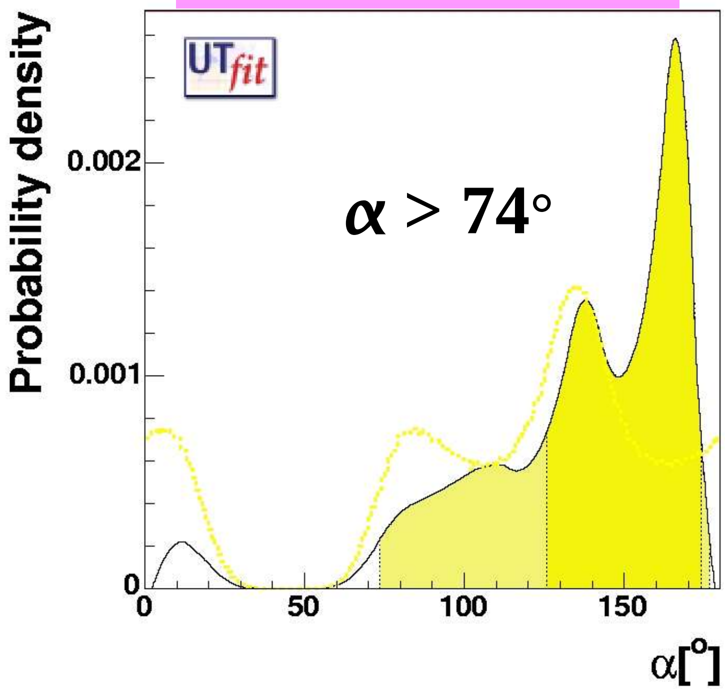
light: 95%

α dall'analisi di isospin (II): $\pi\pi$

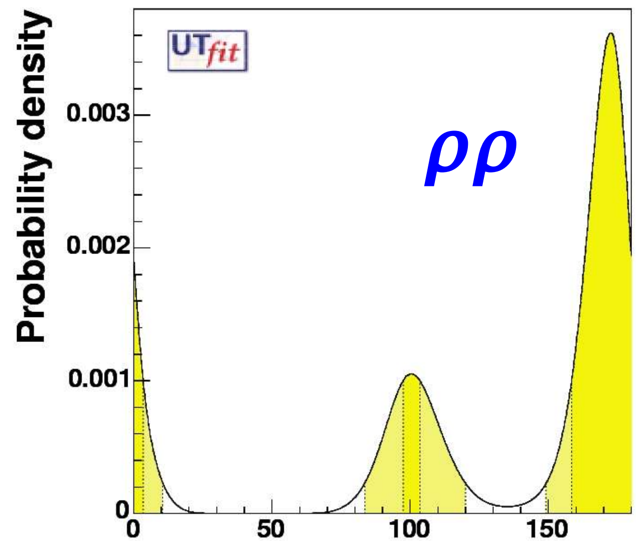
UTfit method: integrating over T, P, T_δ, δ_P, δ_{Tc}

HFAG Moriond 2005

$S_{\pi\pi}$ = -0.50 ± 0.12
$C_{\pi\pi}$ = -0.37 ± 0.10



scuro: 65%
chiaro: 95%



S_{long} = -0.19 ± 0.33 ± 0.11
C_{long} = -0.23 ± 0.24 ± 0.14