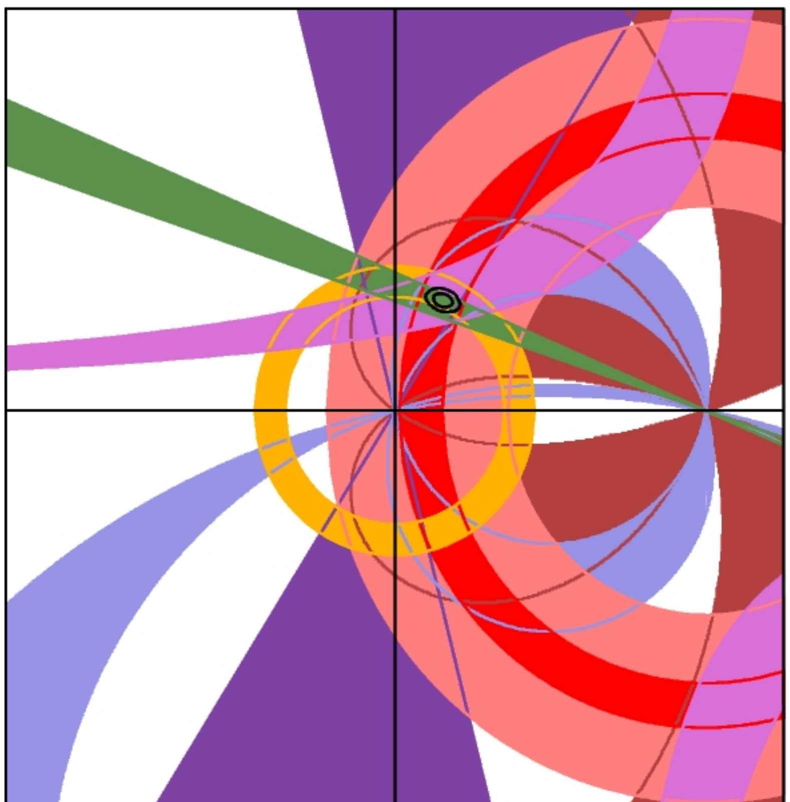
Model-independent new physics analysis with the Unitarity Triangle fit



Marcella Bona

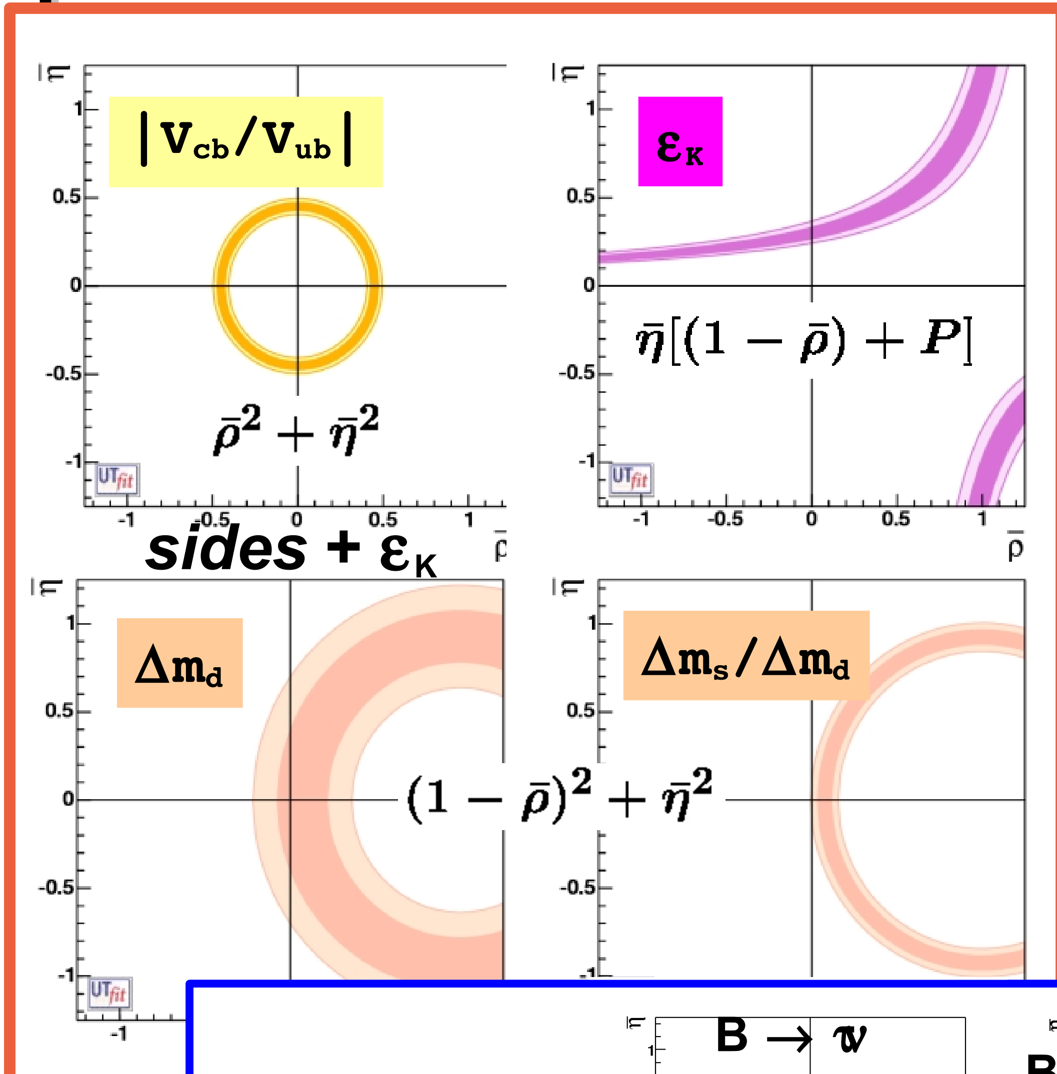
Workshop on New Physics with SuperB,
Warwick University,
April 15th, 2009

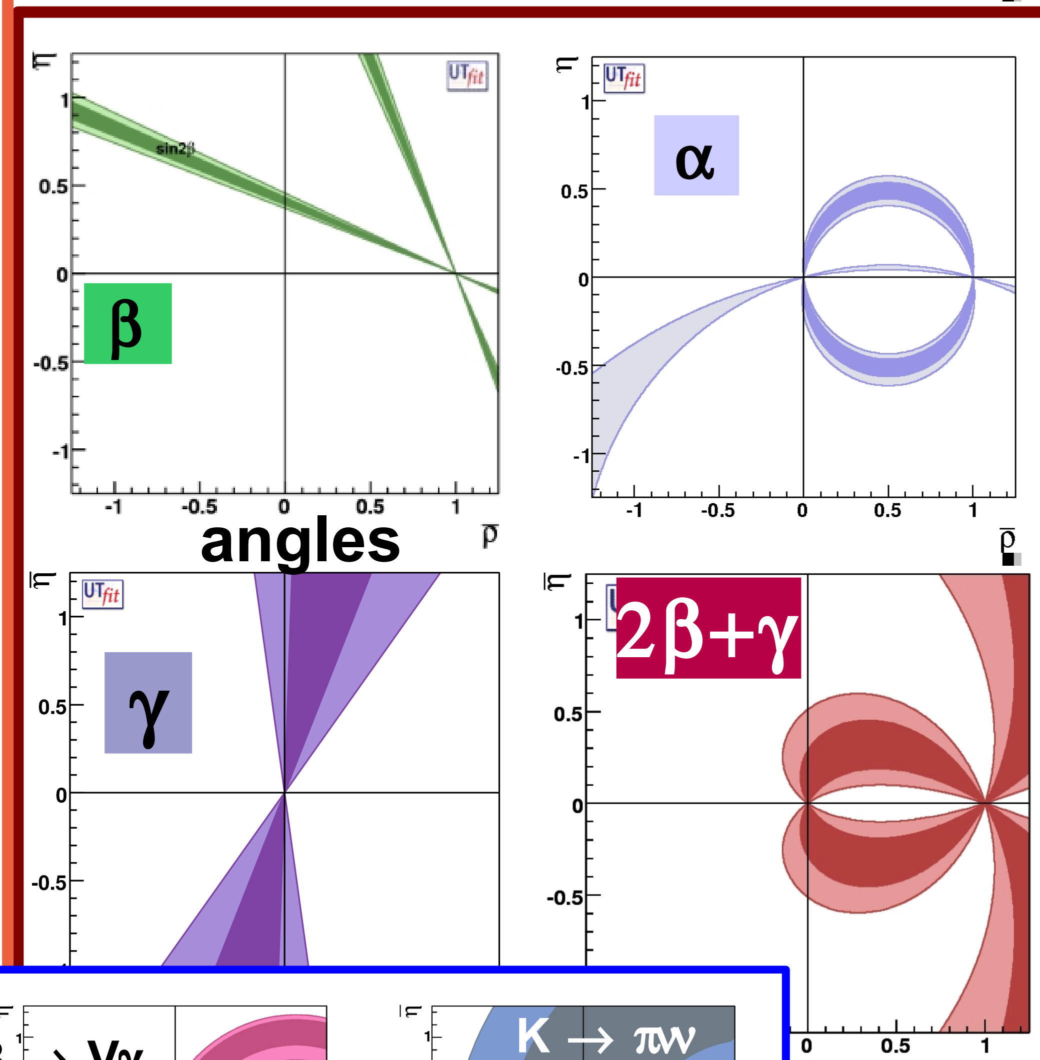
UTfit

www.utfit.org

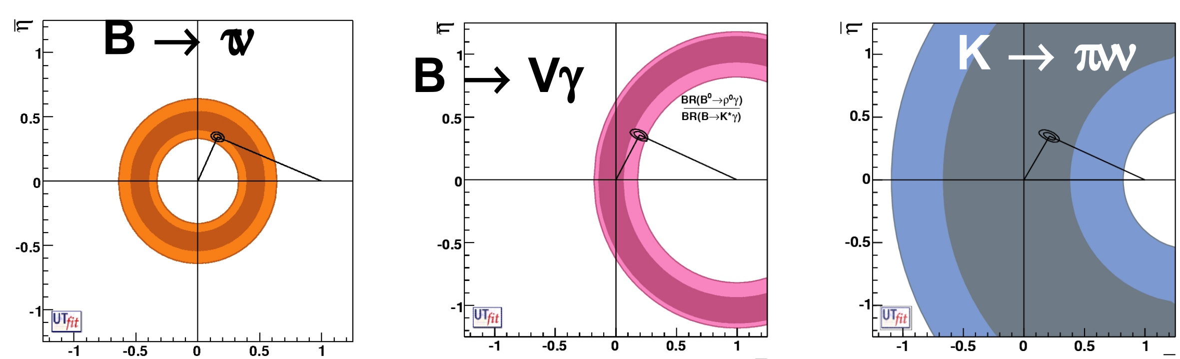
M.B., M. Ciuchini, E. Franco, V. Lubicz,
G. Martinelli, F. Parodi, M. Pierini,
C. Schiavi, L. Silvestrini, A. Stocchi,
V. Sordini, C. Tarantino and V. Vagnoni

Unitarity Triangle analysis in the SM

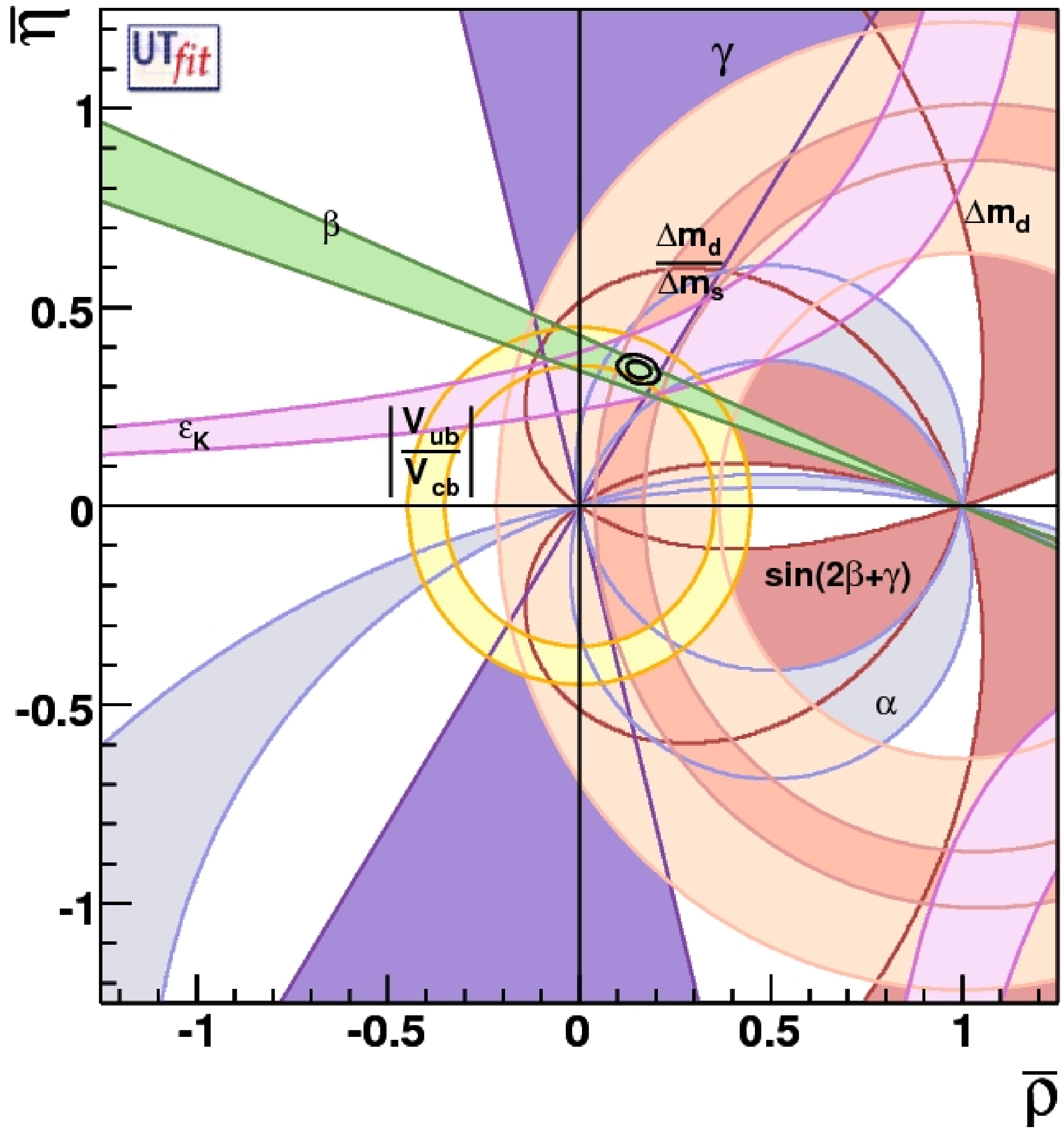




rare decays:



Unitarity Triangle analysis in the SM

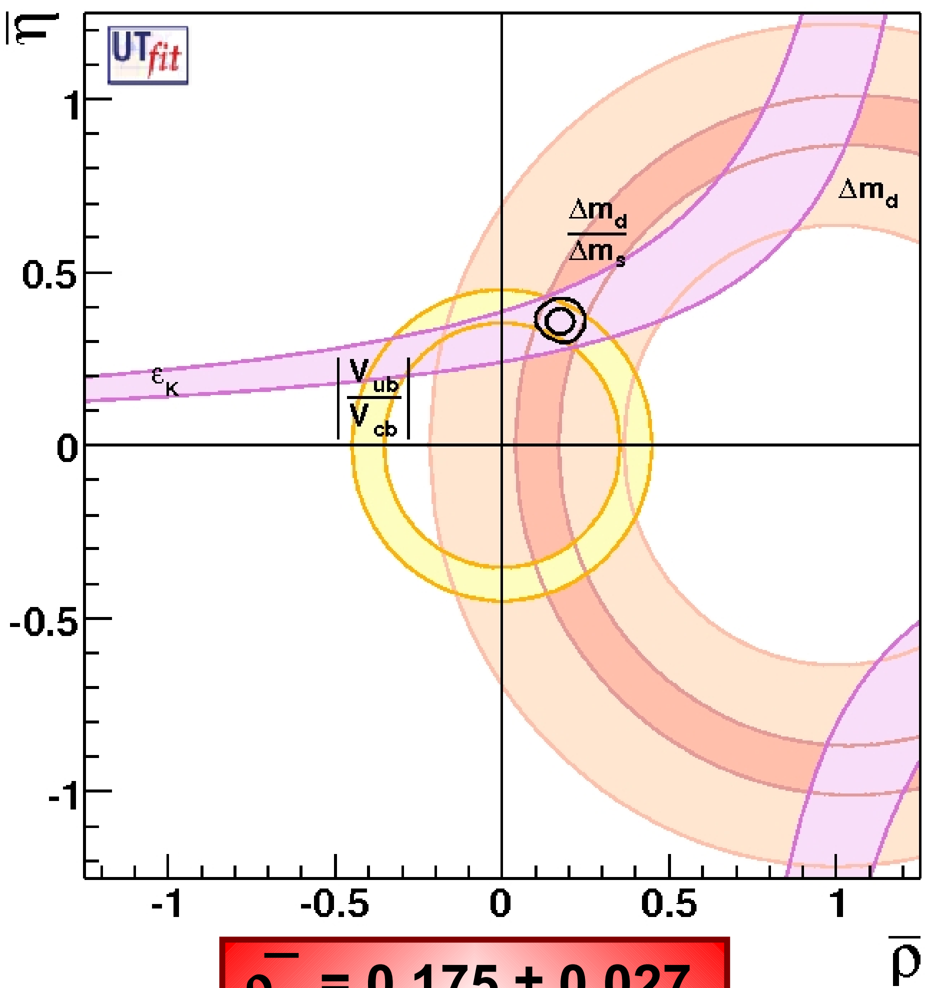


$\bar{\rho} = 0.155 \pm 0.022$
$\bar{\eta} = 0.342 \pm 0.014$

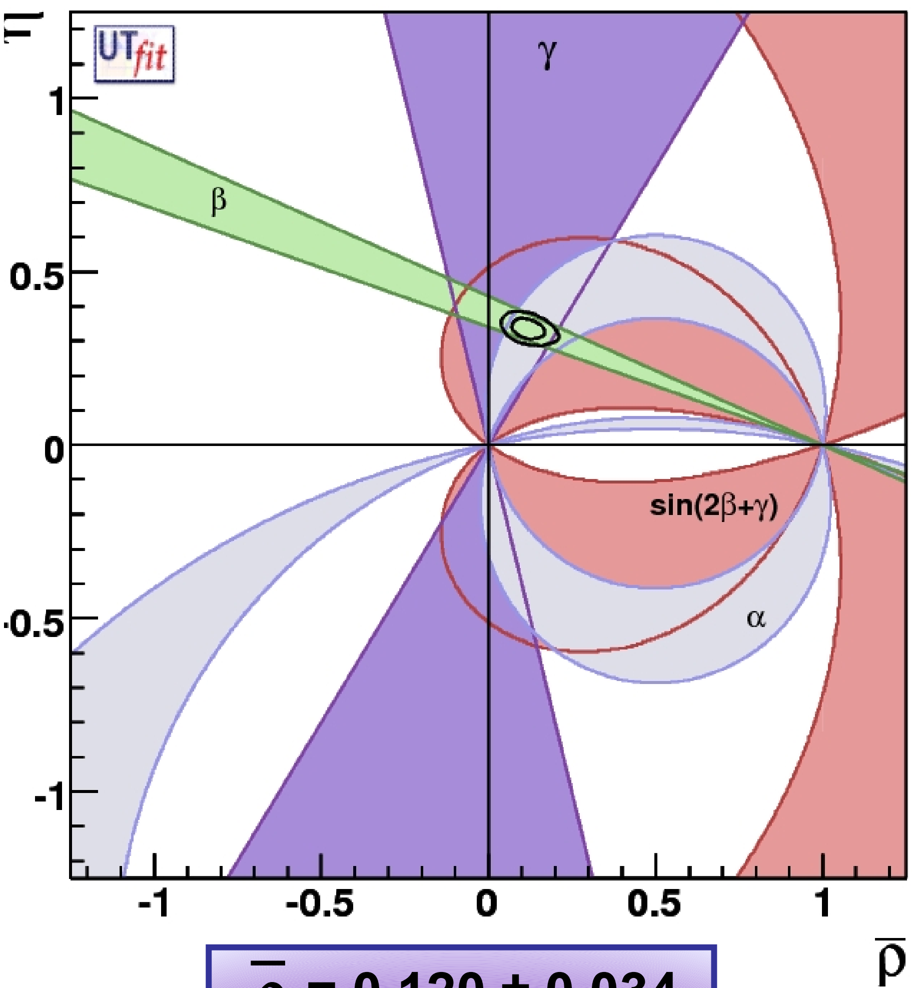
- Data in agreement
- NP, if any, seems not to introduce additional CP or flavour violation in b ↔ d transitions at current experimental precision

the LEP-style analysis vs the angle analysis

levels @ 95% Prob



$\bar{\rho}$ = 0.175 ± 0.027
$\bar{\eta}$ = 0.360 ± 0.023

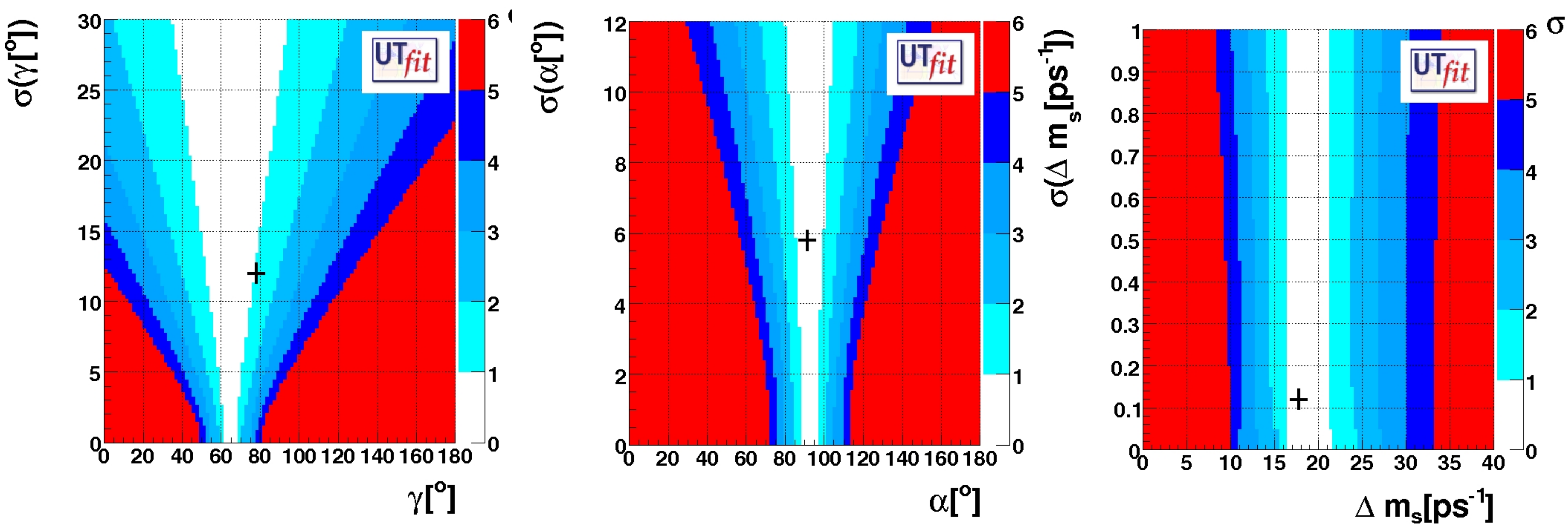


$\bar{\rho}$ = 0.120 ± 0.034
$\bar{\eta}$ = 0.335 ± 0.020

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

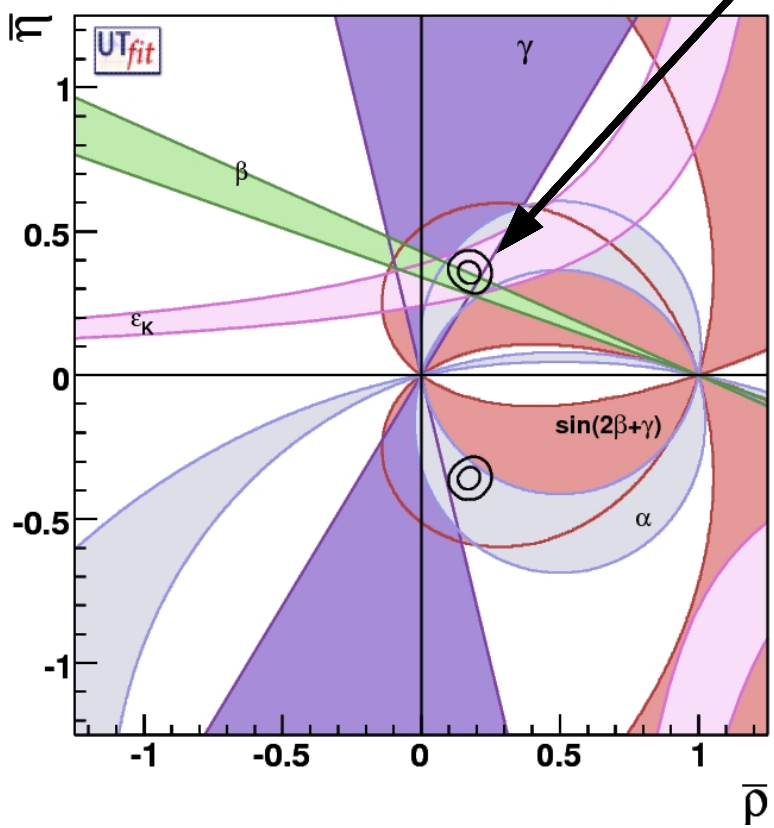
The cross has the coordinates (x,y)=(central value, error) of the direct measurement

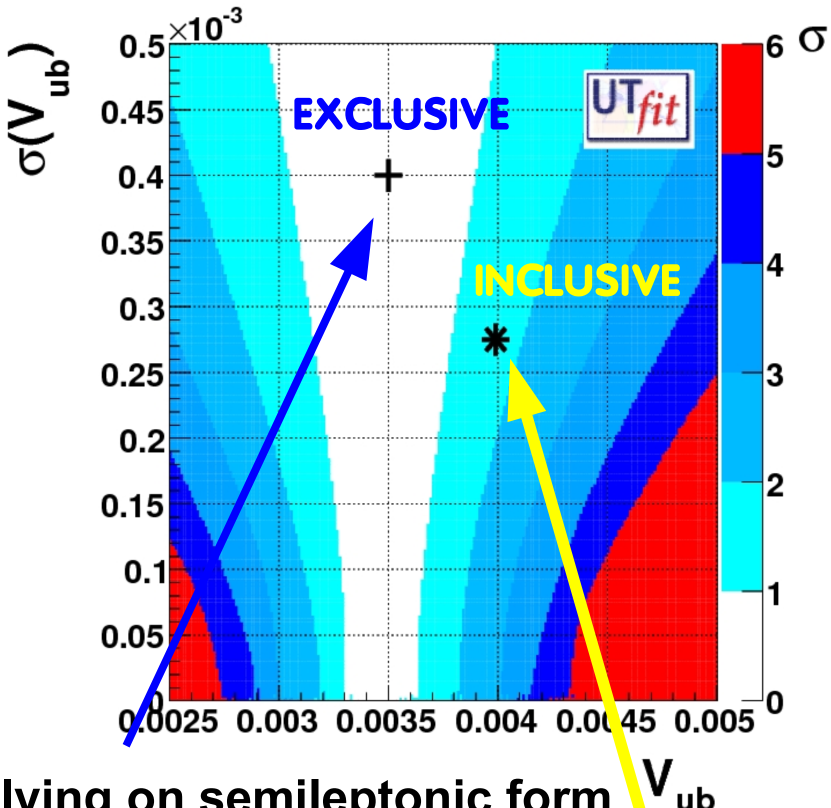


Color code: agreement between the predicted values and the measurements at better than 1, 2, ...nσ

the current status of the *tension*

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





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

$Vub_{excl} = (35.0 \pm 4.0) \cdot 10^{-4}$

$Vub_{UTfit} = (34.8 \pm 1.6) \cdot 10^{-4}$

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

$Vub_{incl} = (39.9 \pm 1.5 \pm 4.0) \cdot 10^{-4}$

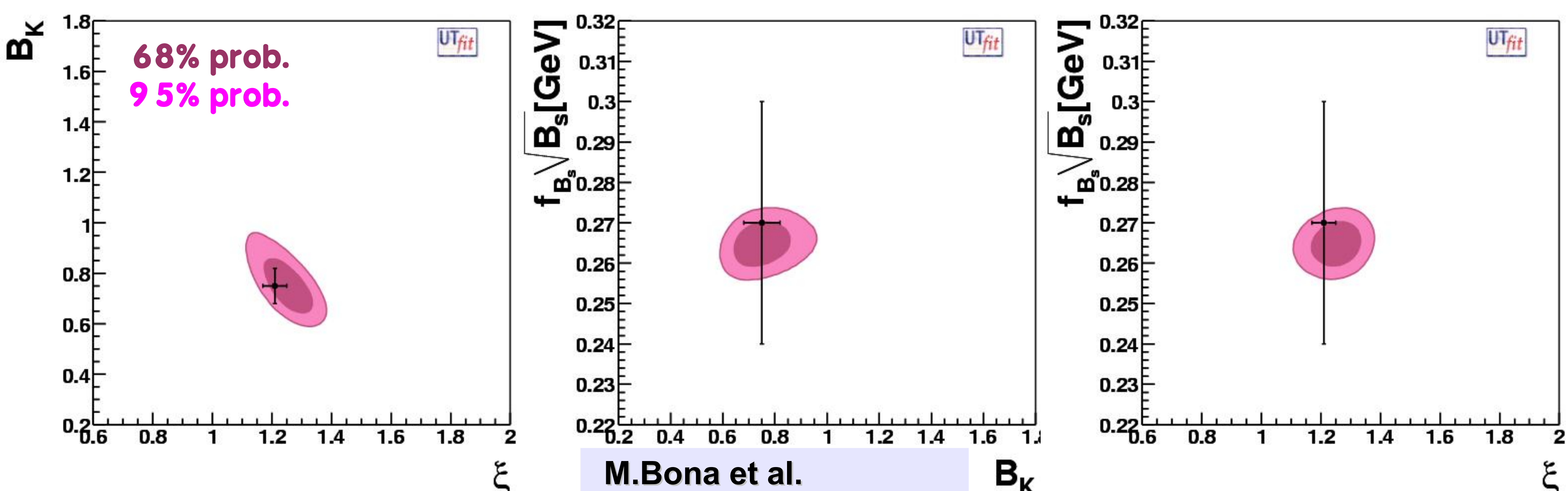
some a-posteriori determinations: lattice QCD

- Through the Standard Model Unitarity Triangle analysis, without using the lattice inputs, we also obtain the updated values of the predictions for the lattice parameters

$B_K^{UT} = 0.75 \pm 0.07$
$f_{Bs}\sqrt{B_{Bs}}^{UT} = 265 \pm 4$ MeV
$\xi^{UT} = 1.26 \pm 0.05$

$B_K^{lat} = 0.75 \pm 0.07$
$f_{Bs}\sqrt{B_{Bs}}^{lat} = 270 \pm 30$ MeV
$\xi^{lat} = 1.21 \pm 0.04$

Averages by UTfit: V. Lubicz, C. Tarantino



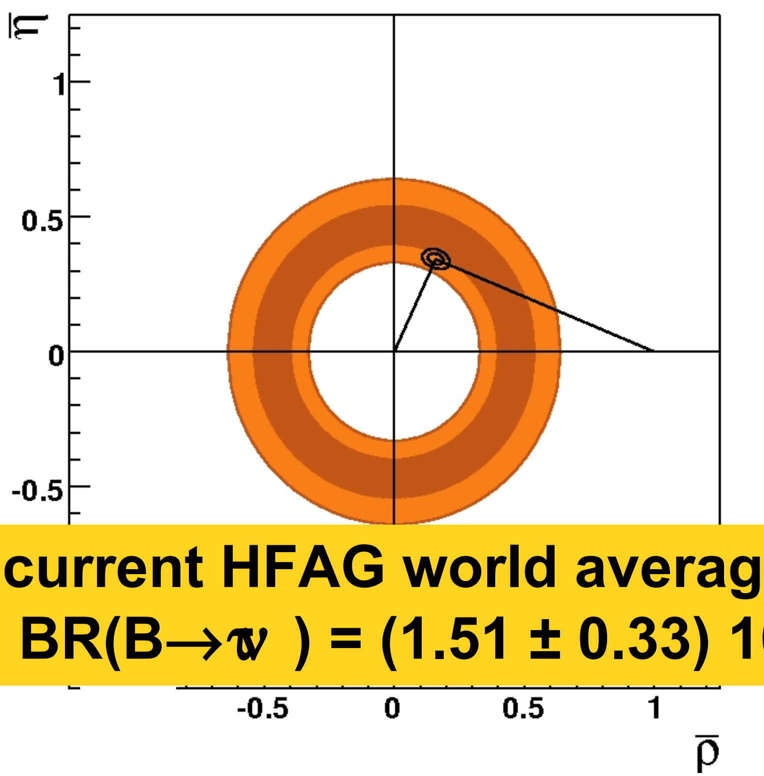
M.Bona et al.
JHEP 0610:081, 2006
(hep-ph/0606167)

some standard model determinations: B→τν

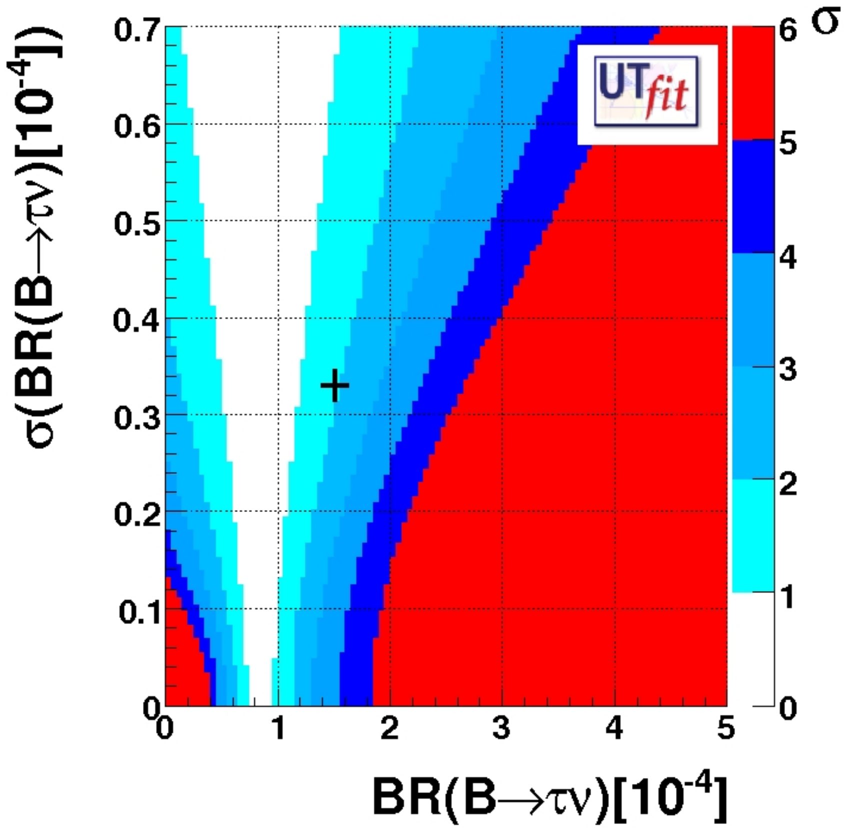
$$\mathcal{B}(B \to \ell\nu) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

SM prediction enhanced or reduced by factor r_H:

$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$



current HFAG world average
BR(B→τν) = (1.51 ± 0.33) 10^{-4}



indirect determination from UT without using lattice QCD and V_{ub}
BR(B→τν) = (0.73 ± 0.12) 10^{-4}

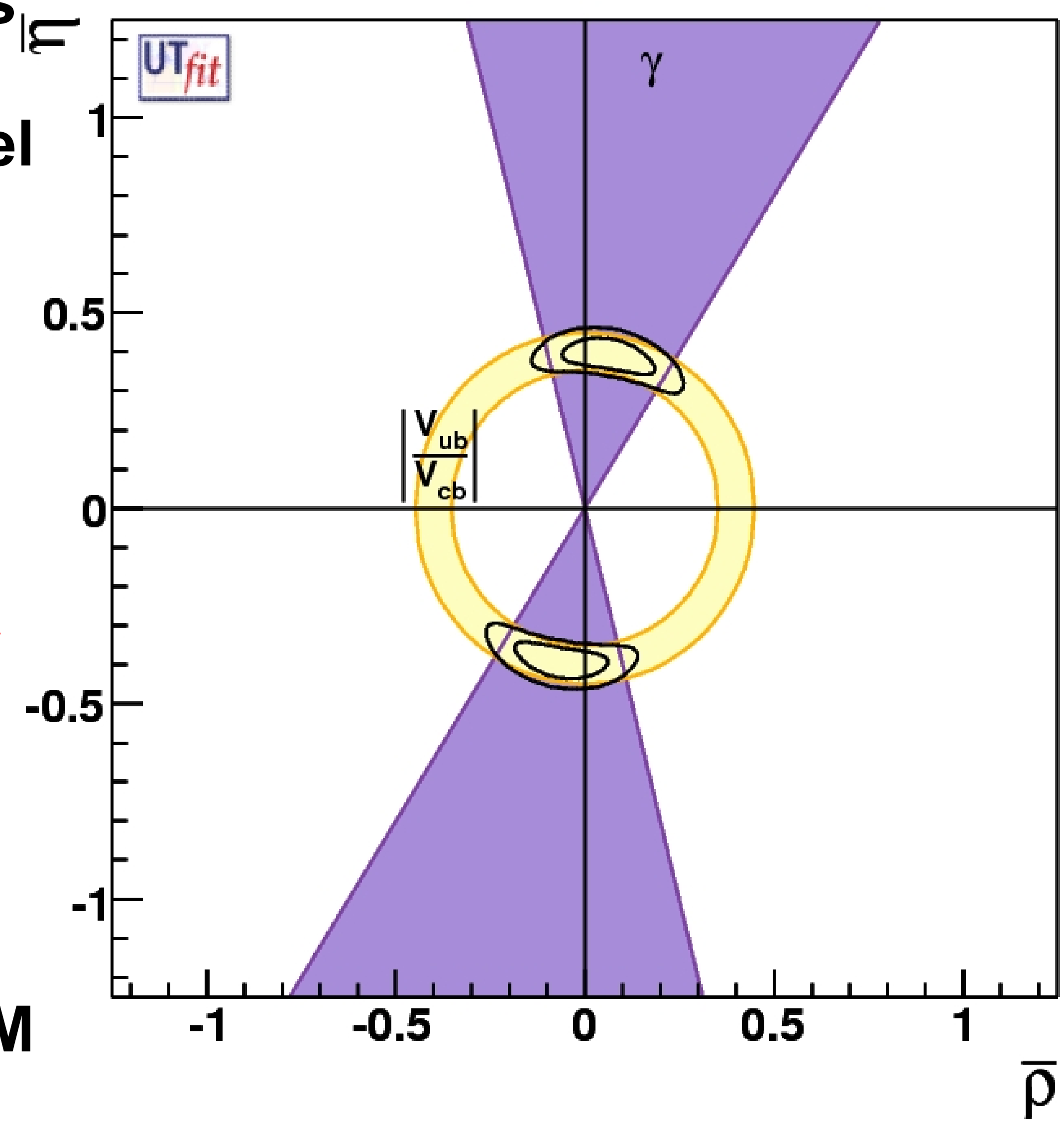
the tree level fit:

B factories are constraining the UT with tree-level processes

Assuming no NP at tree level
(the effect of the $\overline{D}$-D^0 mixing to γ are small wrt the present error and can be accounted for in the future)

We can determine $\overline{\rho}$ and $\overline{\eta}$ regardless of NP

$$\overline{\rho} = \pm\, 0.06 \pm 0.08$$
$$\overline{\eta} = \pm\, 0.39 \pm 0.03$$



Values in agreement with SM within the errors

UT analysis including new physics (NP)

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

$$C_{B_s} e^{-2i\phi_{B_s}} = \frac{\langle \overline{B}_s | H_{eff}^{SM} + H_{eff}^{NP} | B_s \rangle}{\langle \overline{B}_s | H_{eff}^{SM} | B_s \rangle} = 1 + \frac{A_{NP} e^{-2i\phi_{NP}}}{A_{SM} e^{-2i\beta_s}}$$

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 distinct theoretical issues)

$$C_{\varepsilon_K} = \frac{\mathrm{Im}\langle K^0 | H_{eff}^{full} | \overline{K}^0 \rangle}{\mathrm{Im}\langle K^0 | H_{eff}^{SM} | \overline{K}^0 \rangle}$$

$$C_{\Delta m_K} = \frac{\mathrm{Re}\langle K^0 | H_{eff}^{full} | \overline{K}^0 \rangle}{\mathrm{Re}\langle K^0 | H_{eff}^{SM} | \overline{K}^0 \rangle}$$

UT analysis including new physics (NP)

M. Bona *et al.* (UTfit)
Phys.Rev.Lett.97:151803,2006

	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 X		
$\Delta\Gamma_d/\Gamma_d$	X	X X		
$\Delta\Gamma_s/\Gamma_s$	X			X X
Δm_s				X
A_{CH}	X	X X		X X

model independent assumptions

SM	→ SM+NP
tree level	
$(V_{ub}/V_{cb})^{SM}$	$(V_{ub}/V_{cb})^{SM}$
γ^{SM}	γ^{SM}
Bd Mixing	
β^{SM}	$\beta^{SM}+\phi_{Bd}$
α^{SM}	$\alpha^{SM}-\phi_{Bd}$
Δm_d	$C_{Bd}\Delta m_d$
Bs Mixing	
Δm_s^{SM}	$C_{Bs}\Delta m_s^{SM}$
β_s^{SM}	$\beta_s^{SM}+\phi_{Bs}$
K Mixing	
ε_K^{SM}	$C_{\varepsilon K}\varepsilon_K^{SM}$

new-physics-specific constraints

$$A_{\mathrm{SL}}^{s} \equiv \frac{\Gamma(\bar{B}_s \to \ell^+ X) - \Gamma(B_s \to \ell^- X)}{\Gamma(\bar{B}_s \to \ell^+ X) + \Gamma(B_s \to \ell^- X)} = \mathrm{Im}\left(\frac{\Gamma_{12}^{s}}{A_s^{\mathrm{full}}}\right)$$

- **semileptonic asymmetry A_{SL}:**
  sensitive to NP effect on both size and phase of B mixing

Laplace et al. Phys.Rev.D 65: 094040,2002

$$A_{\mathrm{SL}}^{s} \times 10^2 = -0.20 \pm 1.19$$

D0 ICHEP08

- **same-side dilepton charge asymmetry A_{CH}:**
  admixture of B_d and B_s dependent on $\bar{\rho}$ and $\bar{\eta}$ and on NP effects

$$A_{\mathrm{SL}}^{\mu\mu} \times 10^3 = -4.3 \pm 3.0$$

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

- **lifetime τ_s in flavour-specific final states:**
  fit for a single exponential for B_s and $\bar{B}_s$ the average lifetime is a function of the width and width difference

$$\tau_{B_s}^{\mathrm{FS}}\ [\mathrm{ps}] = 1.461 \pm 0.032$$

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

Dunietz et al., hep-ph 0012219

new-physics-specific constraints (II)

◉ $\Delta\Gamma$ for B_d and B_s

B meson mixing matrix element NLO calculation
Ciuchini et al. JHEP 0308:031,2003.

$$\frac{\Gamma_{12}^q}{A_q^{\text{full}}} = -2\frac{\kappa}{C_{B_q}}\left\{e^{2\phi_{B_q}}\left(n_1 + \frac{n_6 B_2 + n_{11}}{B_1}\right) - \frac{e^{(\phi_q^{\text{SM}}+2\phi_{B_q})}}{R_t^q}\left(n_2 + \frac{n_7 B_2 + n_{12}}{B_1}\right) + \frac{e^{2(\phi_q^{\text{SM}}+\phi_{B_q})}}{R_t^{q^2}}\left(n_3 + \frac{n_8 B_2 + n_{13}}{B_1}\right) + e^{(\phi_q^{\text{Pen}}+2\phi_{B_q})} C_q^{\text{Pen}}\left(n_4 + n_9\frac{B_2}{B_1}\right) - e^{(\phi_q^{\text{SM}}+\phi_q^{\text{Pen}}+2\phi_{B_q})}\frac{C_q^{\text{Pen}}}{R_t^q}\left(n_5 + n_{10}\frac{B_2}{B_1}\right)\right\}$$

C_{pen} and ϕ_{pen} are parameterize possible NP contributions from $b \to s$ penguins

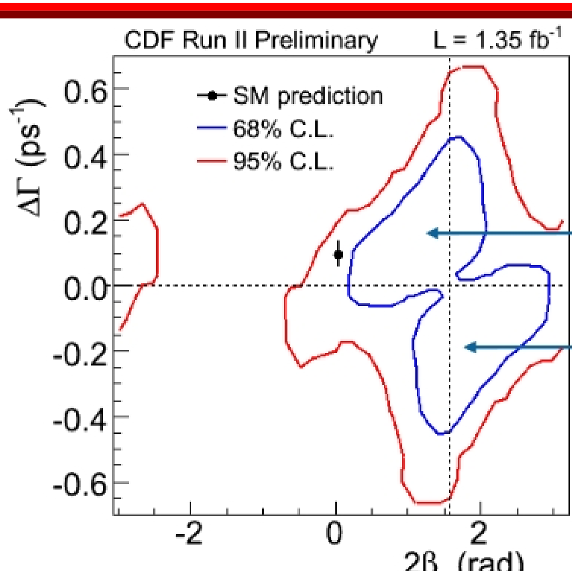
◉ $\phi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$

ϕ_s and $\Delta\Gamma_s$: 2D experimental likelihood from CDF and D0

Standard Model expectations:
(arXiv:hep-ph/0612167)

$\Delta\Gamma_s = 0.096 \pm 0.039\ \text{ps}^{-1}$
$2\beta_s = 0.04 \pm 0.01$ rad

Standard Model p_{value} = 15% (1.5σ)

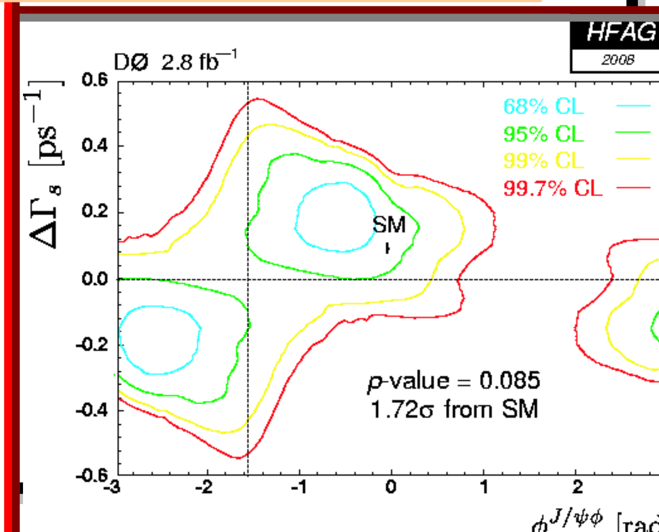


strong phases can separate the two minima

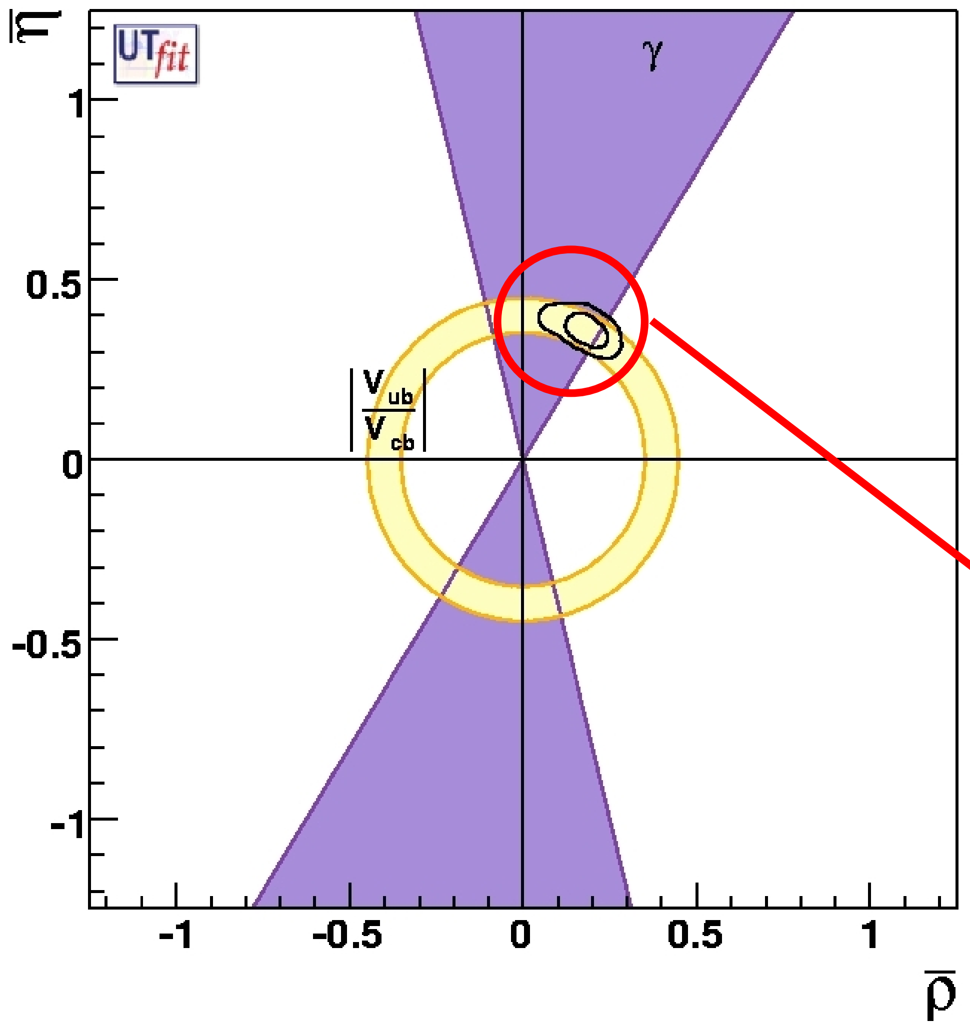
$\cos(\delta_\perp) < 0$
$\cos(\delta_\perp - \delta_\parallel) > 0$

$\cos(\delta_\perp) > 0$
$\cos(\delta_\perp - \delta_\parallel) < 0$

Δm_s constraint to $17.77 \pm 0.12\ \text{ps}^{-1}$



UT analysis including NP



$\bar{\rho}$ = 0.177 ± 0.044
$\bar{\eta}$ = 0.360 ± 0.031

Allowing for NP we go back to the SM solution

$\bar{\rho}$ = 0.155 ± 0.022
$\bar{\eta}$ = 0.342 ± 0.014

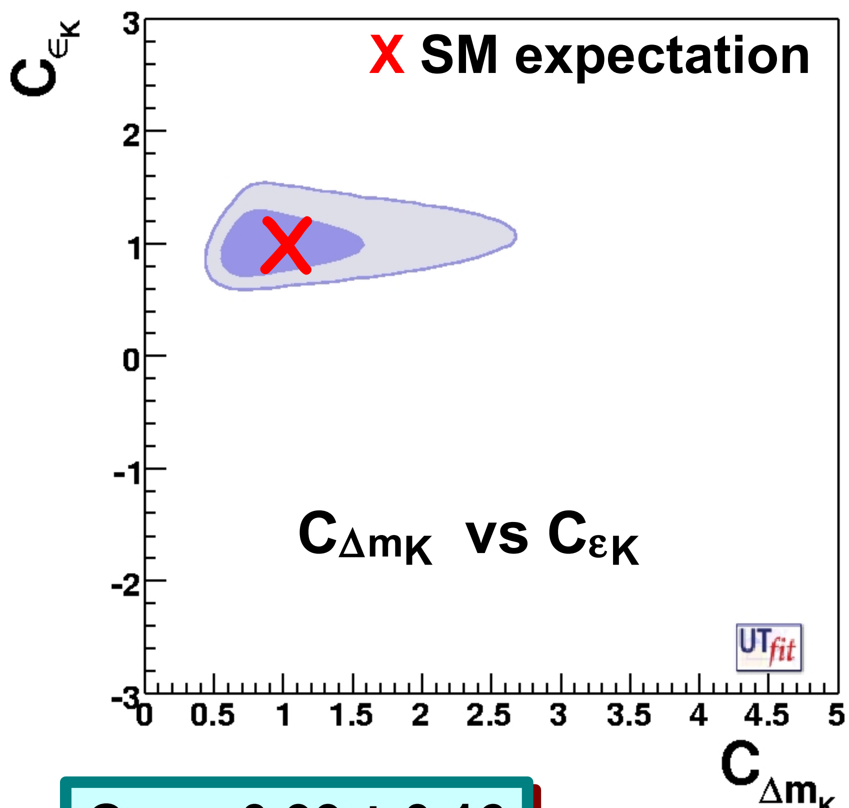
before the B factories:
the uncertainty on CKM parameters with NP was the limiting factor.

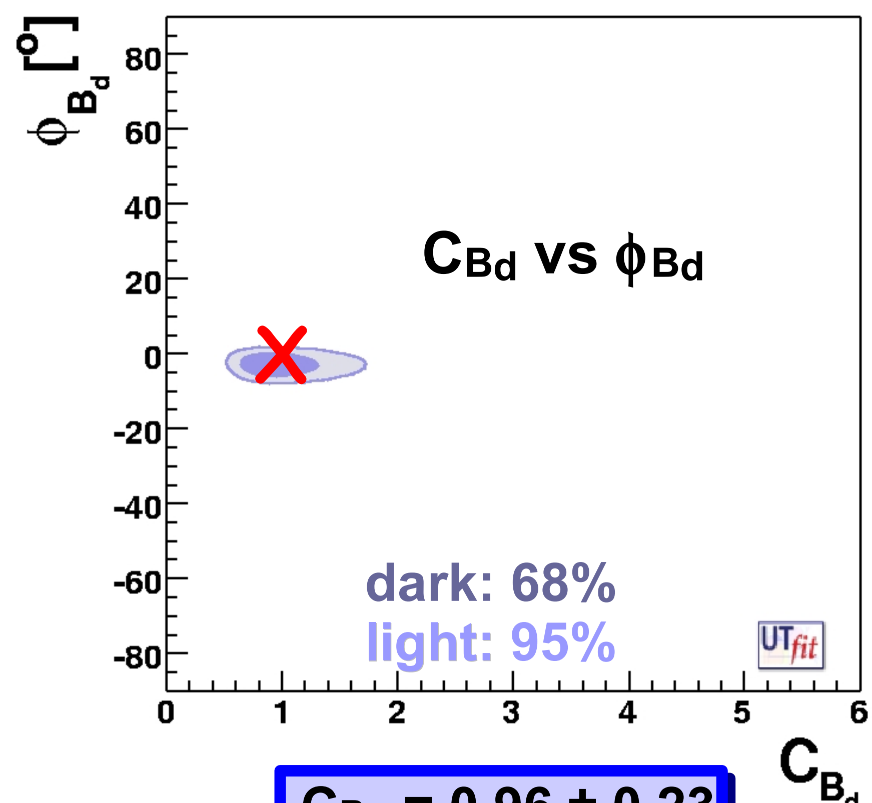
NP parameters in the K & B_d sectors

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

$$\Delta m_K = C_{\Delta m_K} (\Delta m_K)^{SM}$$
$$\varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

$$C_{B_q} e^{2i\phi_{B_q}} = \frac{\langle B_q | H_{\rm eff}^{\rm full} | \bar{B}_q \rangle}{\langle B_q | H_{\rm eff}^{\rm SM} | \bar{B}_q \rangle}$$





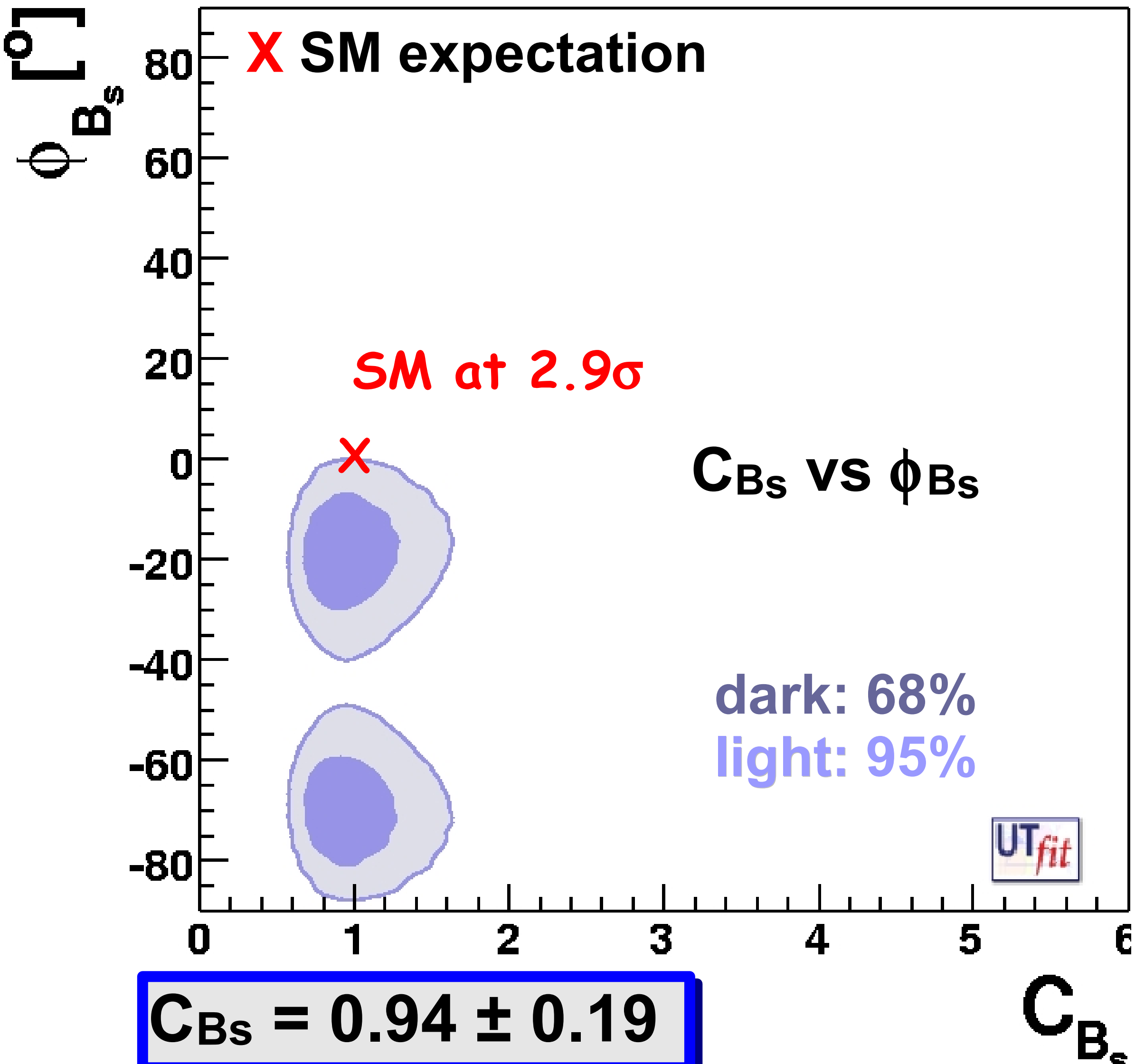
$C\varepsilon_K = 0.99 \pm 0.16$

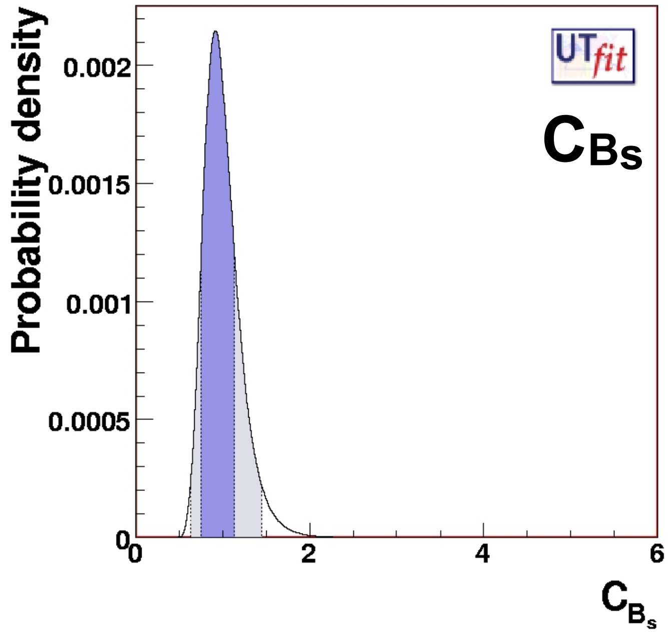
$C\Delta m_K = 0.96 \pm 0.34$

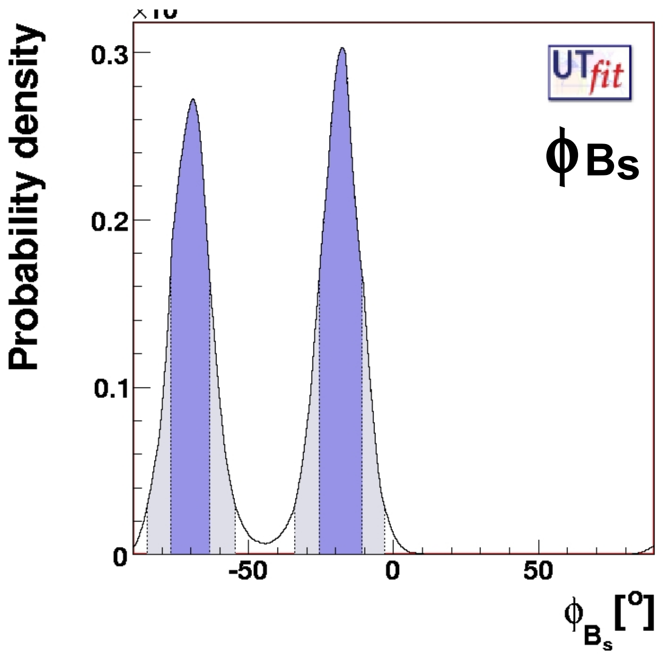
$C_{Bd} = 0.96 \pm 0.23$

$\phi_{Bd} = (-2.9 \pm 1.9)°$

NP parameters in the B_s sector







$C_{Bs} = 0.94 \pm 0.19$

$\phi_{Bs} = (-69 \pm 7)° \cup (-19 \pm 8)°$

Testing the new-physics scale

At the high scale

new physics enters according to its specific features

At the low scale

use OPE to write the most general effective Hamiltonian. the operators have different chiralities than the SM

NP effects are in the Wilson Coefficients C

$$\mathcal{H}_{\rm eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i Q_i^{bq} + \sum_{i=1}^{3} \tilde{C}_i \tilde{Q}_i^{bq}$$

$$Q_1^{q_i q_j} = \bar{q}_{jL}^{\alpha} \gamma_\mu q_{iL}^{\alpha} \bar{q}_{jL}^{\beta} \gamma^\mu q_{iL}^{\beta} ,$$

$$Q_2^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha} \bar{q}_{jR}^{\beta} q_{iL}^{\beta} ,$$

$$Q_3^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\beta} \bar{q}_{jR}^{\beta} q_{iL}^{\alpha} ,$$

$$Q_4^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\alpha} \bar{q}_{jL}^{\beta} q_{iR}^{\beta} ,$$

$$Q_5^{q_i q_j} = \bar{q}_{jR}^{\alpha} q_{iL}^{\beta} \bar{q}_{jL}^{\beta} q_{iR}^{\alpha} .$$

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 RGE

M. Bona *et al.* (UTfit)
JHEP 0803:049,2008
arXiv:0707.0636

Effective BSM Hamiltonian for ΔF=2 transitions

Most general form of the effective Hamiltonian for ΔF=2 processes

$$\mathcal{H}_{\rm eff}^{K-\bar{K}} = \sum_{i=1}^{5} C_i\, Q_i^{sd} + \sum_{i=1}^{3} \tilde{C}_i\, \tilde{Q}_i^{sd}$$

$$\mathcal{H}_{\rm eff}^{B_q-\bar{B}_q} = \sum_{i=1}^{5} C_i\, Q_i^{bq} + \sum_{i=1}^{3} \tilde{C}_i\, \tilde{Q}_i^{bq}$$

The Wilson coefficients C_i have in general the form

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

Putting bounds on the Wilson coefficients give insights into the NP scale in different NP scenarios that enter through F_i and L_i

- **F_i: function of the NP flavour couplings**
- **L_i: loop factor (in NP models with no tree-level FCNC)**
- **Λ: NP scale (typical mass of new particles mediating ΔF=2 transitions)**

Contribution to the mixing amplitutes

analytic expression for the contribution to the mixing amplitudes

Lattice QCD

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

***arXiv:0707.0636:** for "magic numbers" a,b and c*, $\eta = \alpha_s(\Lambda)/\alpha_s(m_t)$

analogously for the K system

$$\langle \bar{K}^0 | \mathcal{H}_{\rm eff}^{\Delta S=2} | K^0 \rangle_i = \sum_{j=1}^{5} \sum_{r=1}^{5} \left(b_j^{(r,i)} + \eta\, c_j^{(r,i)} \right) \eta^{a_j} C_i(\Lambda)\, R_r \langle \bar{K}^0 | Q_1^{sd} | K^0 \rangle$$

to obtain the p.d.f. for the Wilson coefficients $C_i(\Lambda)$ at the new-physics scale, we switch on one coefficient at a time in each sector and calculate its value from the result of the NP analysis.

Testing the TeV scale

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

The dependence of C on Λ changes on flavor structure.
we can consider different flavour scenarios:

- **Generic**: $C(\Lambda) = \alpha/\Lambda^2$ — $F_i \sim 1$, arbitrary phase
- **NMFV**: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$ — $F_i \sim |F_{SM}|$, arbitrary phase
- **MFV**: $C(\Lambda) = \alpha \times |F_{SM}|/\Lambda^2$ — $F_1 \sim |F_{SM}|$, $F_{i\neq 1} \sim 0$, SM phase

α (L_i) is the coupling among NP and SM

- $\alpha \sim 1$ for strongly coupled NP
- $\alpha \sim \alpha_W$ (α_s) in case of loop coupling through weak (strong) interactions

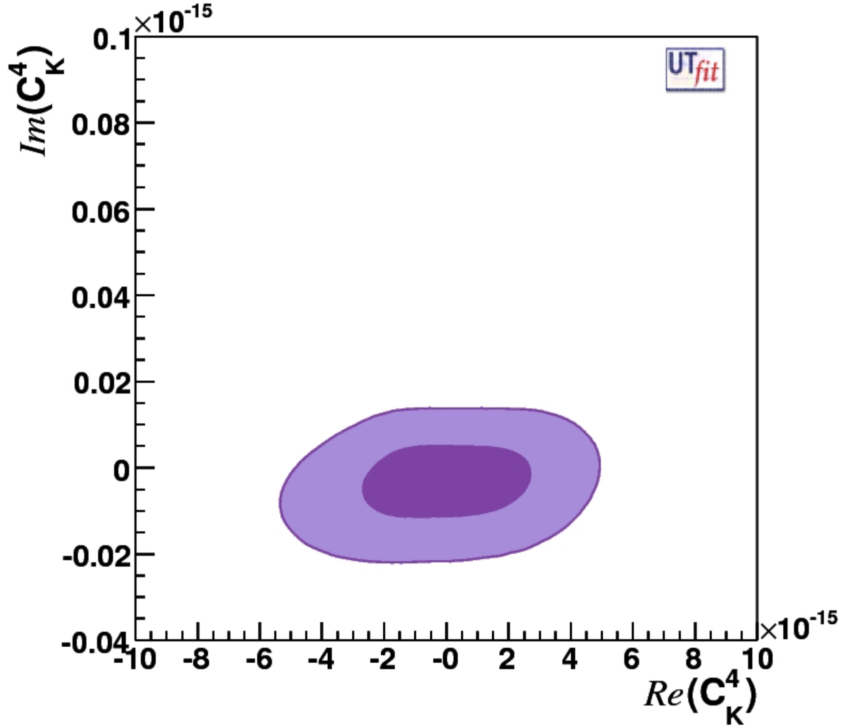
F_{SM} is the combination of CKM factors for the considered process

If no NP effect is seen
lower bound on NP scale Λ
if NP is seen
upper bound on NP scale Λ

Results from the Wilson coefficients

the results obtained for the flavour scenarios:
In deriving the lower bounds on the NP scale, we assume Li = 1, corresponding to strongly-interacting and/or tree-level NP.

Parameter	95% allowed range (GeV^{-2})	Lower limit on Λ (TeV) for arbitrary NP	Lower limit on Λ (TeV) for NMFV
$\mathrm{Re}C_K^1$	$[-9.6, 9.6] \cdot 10^{-13}$	$1.0 \cdot 10^3$	0.35
$\mathrm{Re}C_K^2$	$[-1.8, 1.9] \cdot 10^{-14}$	$7.3 \cdot 10^3$	2.0
$\mathrm{Re}C_K^3$	$[-6.0, 5.6] \cdot 10^{-14}$	$4.1 \cdot 10^3$	1.1
$\mathrm{Re}C_K^4$	$[-3.6, 3.6] \cdot 10^{-15}$	$17 \cdot 10^3$	4.0
$\mathrm{Re}C_K^5$	$[-1.0, 1.0] \cdot 10^{-14}$	$10 \cdot 10^3$	2.4
$\mathrm{Im}C_K^1$	$[-4.4, 2.8] \cdot 10^{-15}$	$1.5 \cdot 10^4$	5.6
$\mathrm{Im}C_K^2$	$[-5.1, 9.3] \cdot 10^{-17}$	$10 \cdot 10^4$	28
$\mathrm{Im}C_K^3$	$[-3.1, 1.7] \cdot 10^{-16}$	$5.7 \cdot 10^4$	19
$\mathrm{Im}C_K^4$	$[-1.8, 0.9] \cdot 10^{-17}$	$24 \cdot 10^4$	62
$\mathrm{Im}C_K^5$	$[-5.2, 2.8] \cdot 10^{-17}$	$14 \cdot 10^4$	37

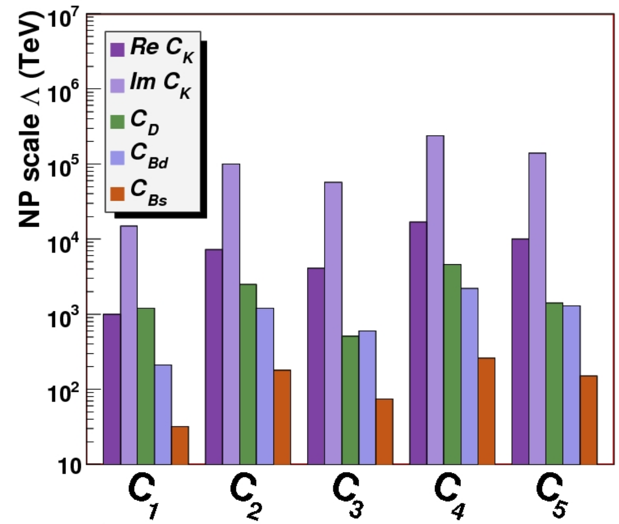


To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by $\alpha_s \sim 0.1$ or by $\alpha_W \sim 0.03$.

Upper and lower bound on the scale

Lower bounds on NP scale from K and B_d physics (in TeV at 95% prob.)

Scenario	strong/tree	α_s loop	α_W loop
MFV	5.5	0.5	0.2
NMFV	62	6.2	2
General	24000	2400	800



Upper bounds on NP scale from B_s:

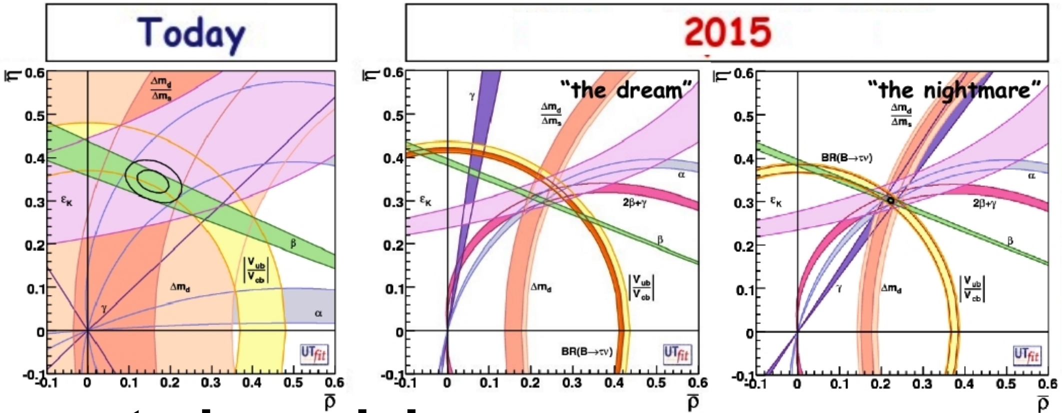
Scenario	strong/tree	α_s loop	α_W loop
NMFV	35	4	2
General	800	80	30

- the **general** case was already problematic (well known flavour puzzle)
- **NMFV** has problems with the size of the B_s effect vs the (insufficient) suppression in B_d and (in particular) K mixing
- **MFV** is OK for the size of the effects, but the B_s phase cannot be generated

Data suggest some hierarchy in NP mixing which is stronger than the SM one

some conclusions

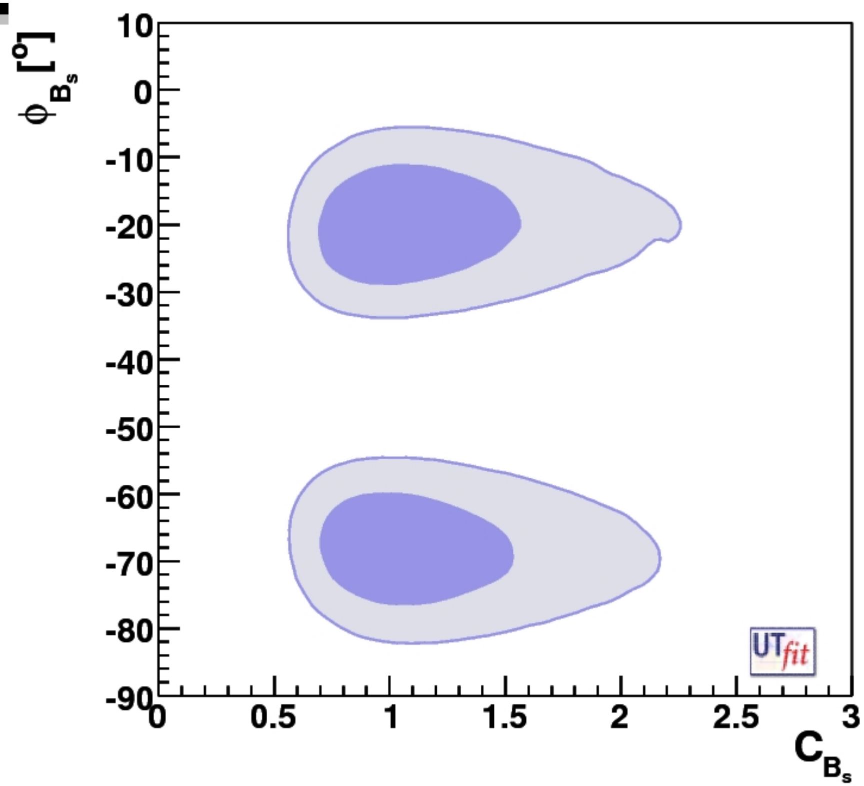
- ◉ **test of the SM consistency and the CKM mechanism: comparison between inputs and indirect determinations**
  - ◎ **Tevatron data show a hint of discrepancy wrt SM: we are looking forward to be able to use the updated results (latest CDF likelihood still not available)**

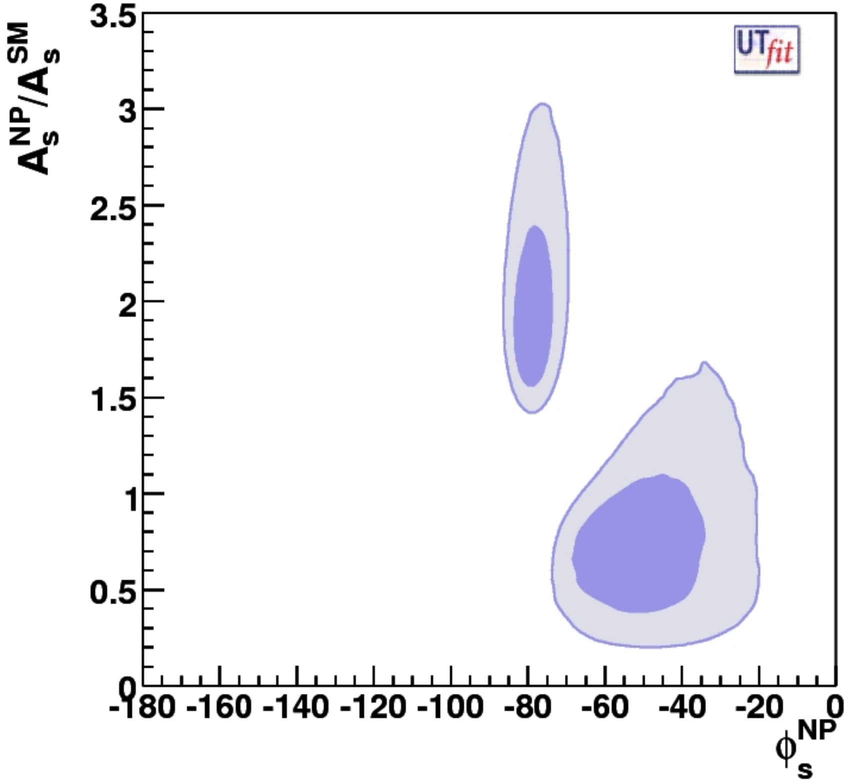


- ◉ **LHCb and superB will reach better precision and provide new measurements**
  - ◎ **an interesting exercise should be to repeat the scale study with the superB expected precisions..**

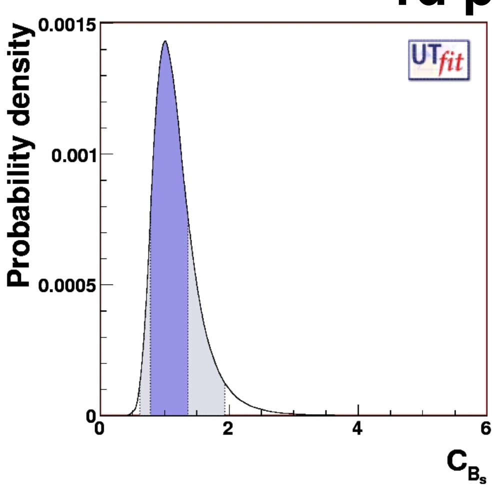
- ◉ **NP scale bounds extracted from model-independent UT fit**
  - ◎ **some models have problems to accommodate the current effects: MFV for B_s, NMFV for B_d vs B_s**
  - ◎ **the generic case is out of reach at LHC**
- ◉ **the challenge is for theory**
  - ◎ **flavour hierarchy needs to be stronger than the CKM λ expansion**

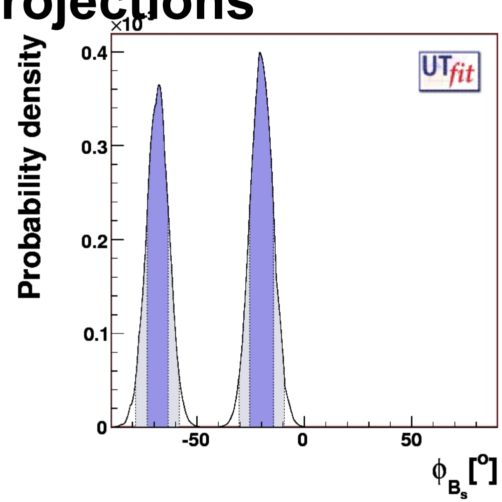
Back-up slides



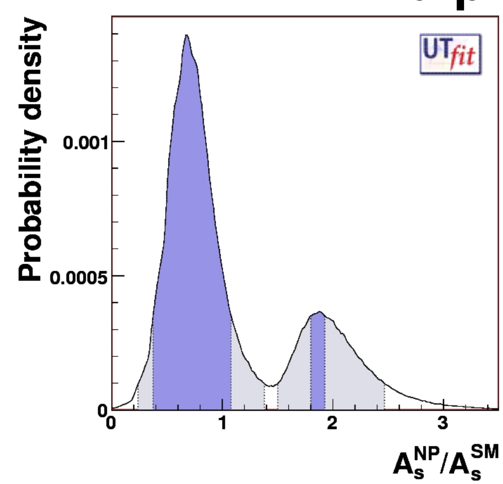


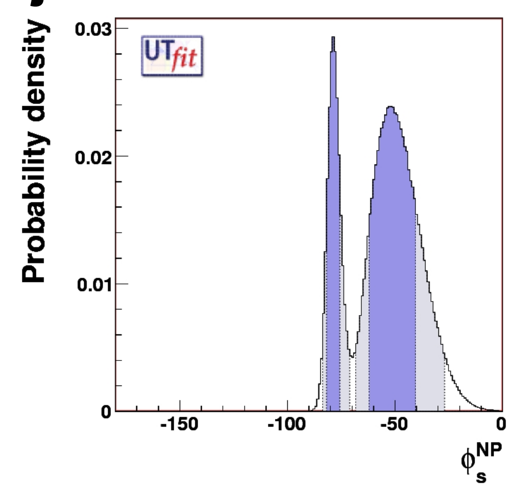
1d projections





1d projections

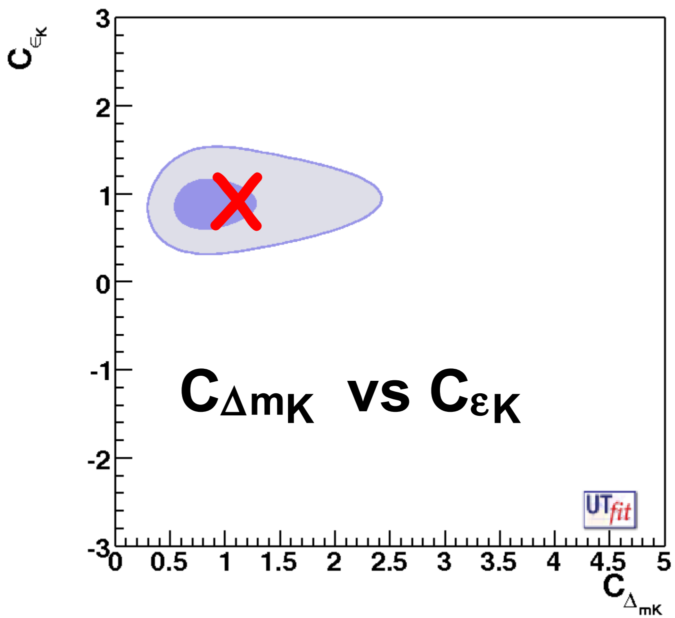


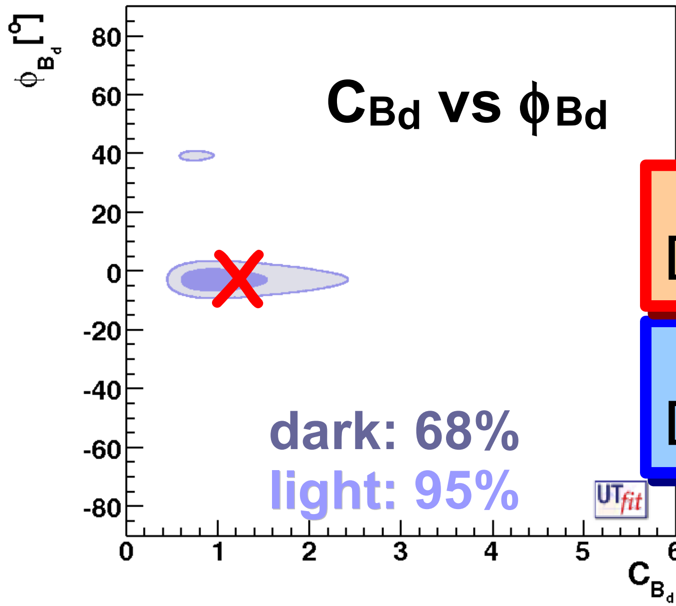


plots from: arXiv:0803.0659 [hep-ph]

The UT*fit* beyond the SM

UTfit Collaboration
arXiv:0803.0659 [hep-ph]

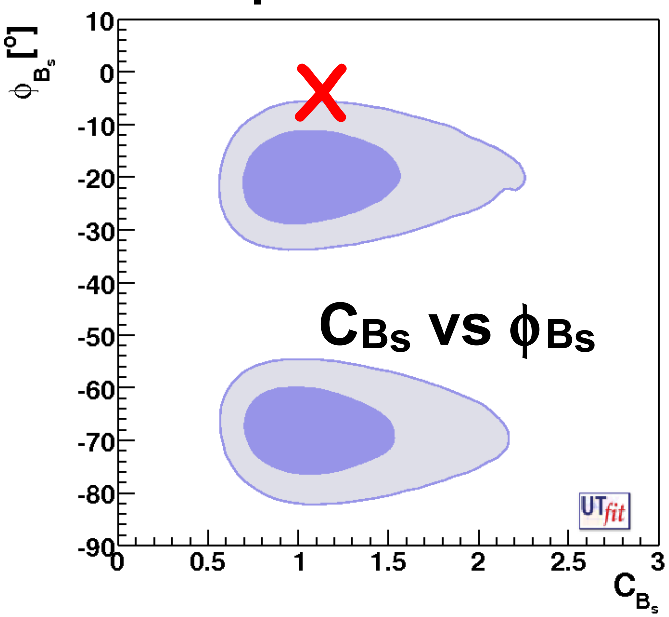




C_{Bd} = 1.00 ± 0.32
[0.51, 1.94] @ 95% Prob.

ϕ_{Bd}=(-3.0 ± 2.2)°
[-7.8°, 1.7°] @ 95% Prob.

X SM expectation



1 – 2: strong suppression
1 – 3: < *O* (10%)
2 – 3: ~ *O* (1)

C_{Bs} = 1.07 ± 0.29
[0.62, 1.93] @ 95% Prob.

ϕ_{Bs}=(-19.9 ± 5.6)°U(-68.2 ± 4.9)°
[-30°, -9°] U [-78°, -58°]@ 95% Prob.

The future of CKM fits

LHCb reach from:
O. Schneider, 1st LHCb Collaboration Upgrade Workshop

SuperB reach from:
SuperB Conceptual Design Report, arXiv:0709.0451

	LHCb 2015 10/fb (5 years)	SuperB 1/ab (1 month at $\Upsilon(5S)$)
Δm_s	0.07%(+0.5%)	no
A^s_{SL}	?	0.006
ϕ_s ($J/\psi\ \phi$)	0.01+syst	0.14
		75/ab (5 years)
$\sin 2\beta$ ($J/\psi\ K_S$)	0.010	0.005
γ (all methods)	2.4°	1-2°
α (all methods)	4.5°	1-2°
$\lvert V_{cb}\rvert$ (all methods)	no	< 1%
$\lvert V_{ub}\rvert$ (all methods)	no	1-2%

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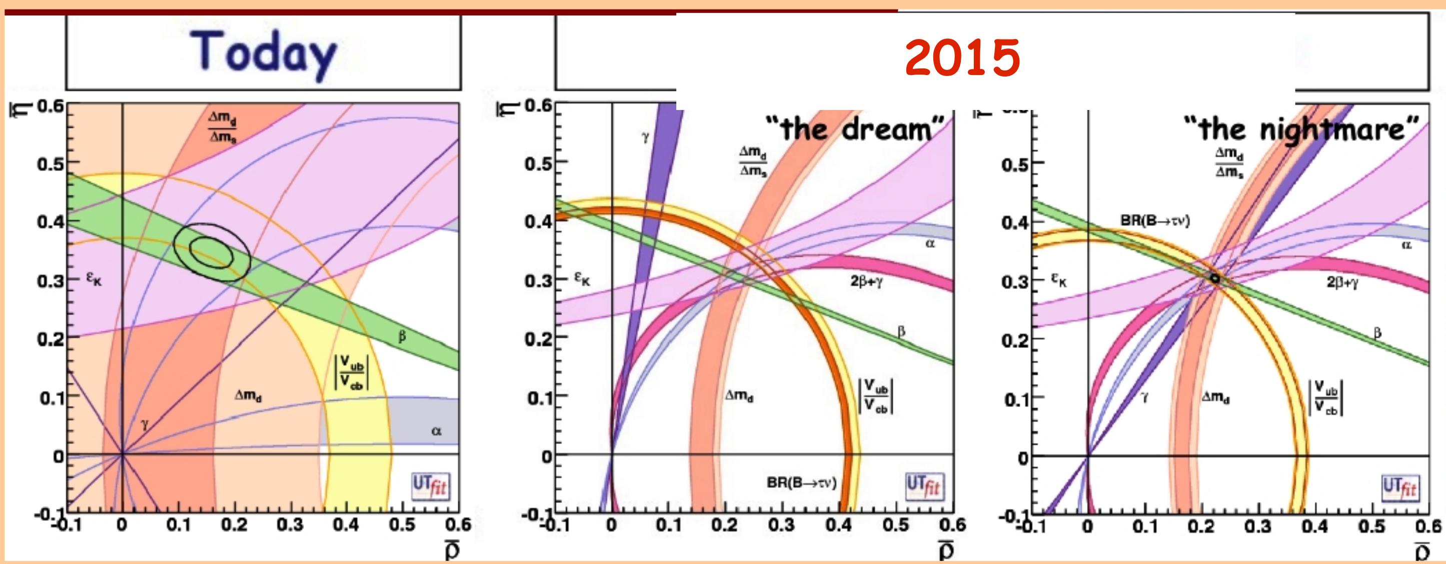
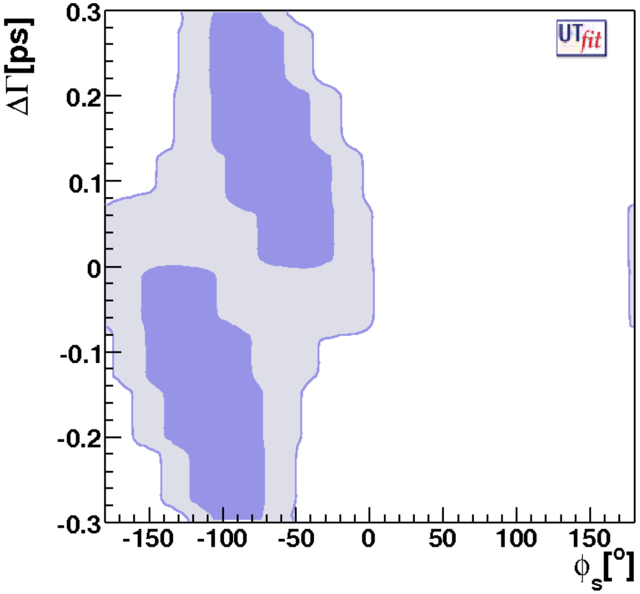
Hadronic matrix element	Current lattice error	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9% (22% on 1-f_+)	0.4% (10% on 1-f_+)	< 0.1% (2.4% on 1-f_+)
$\hat{B}_K$	11%	3%	1%
f_B	14%	2.5 - 4.0%	1 – 1.5%
$f_{B_s} B_{B_s}^{1/2}$	13%	3 - 4%	1 – 1.5%
ξ	5% (26% on ξ-1)	1.5 - 2 % (9-12% on ξ-1)	0.5 – 0.8 % (3-4% on ξ-1)
$\mathcal{F}_{B\to D/D^*l\nu}$	4% (40% on 1-$\mathcal{F}$)	1.2% (13% on 1-$\mathcal{F}$)	0.5% (5% on 1-$\mathcal{F}$)
$f_+^{B\pi}, \ldots$	11%	4 - 5%	2 – 3%
$T_1^{B\to K^*/\rho}$	13%	----	3 – 4%

S.Sharpe @ Lattice QCD: Present and Future, Orsay, 2004 and report of the U.S. Lattice QCD Executive Committee

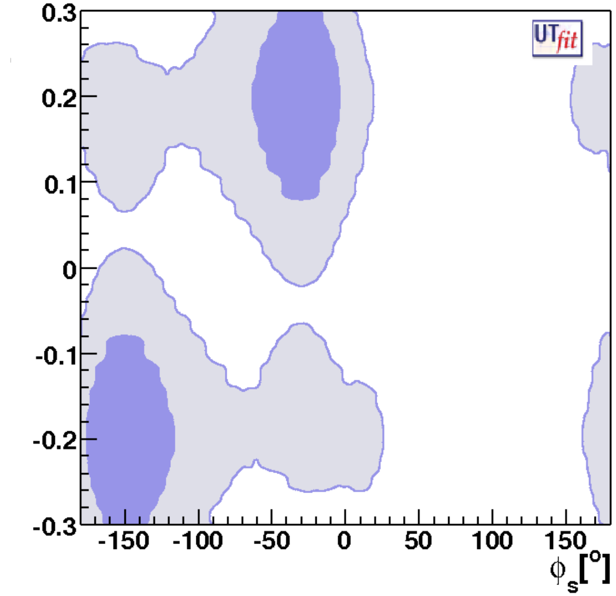


More than two measurements (I)

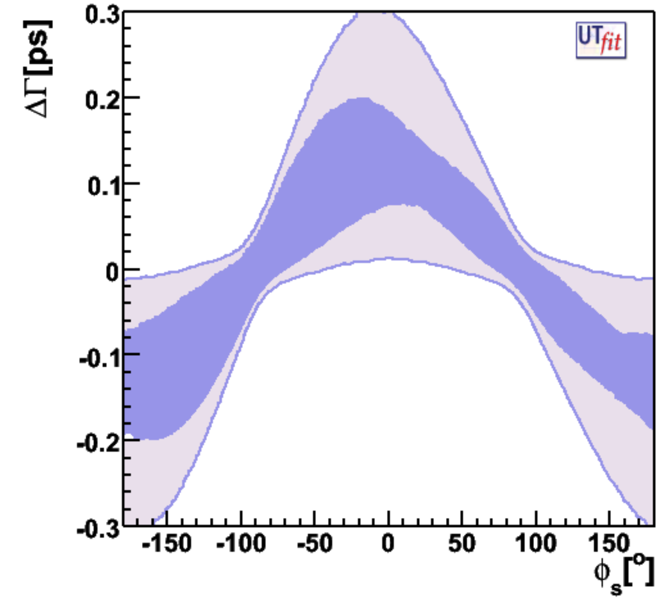
CDF tagged measurement



D0 tagged measurement



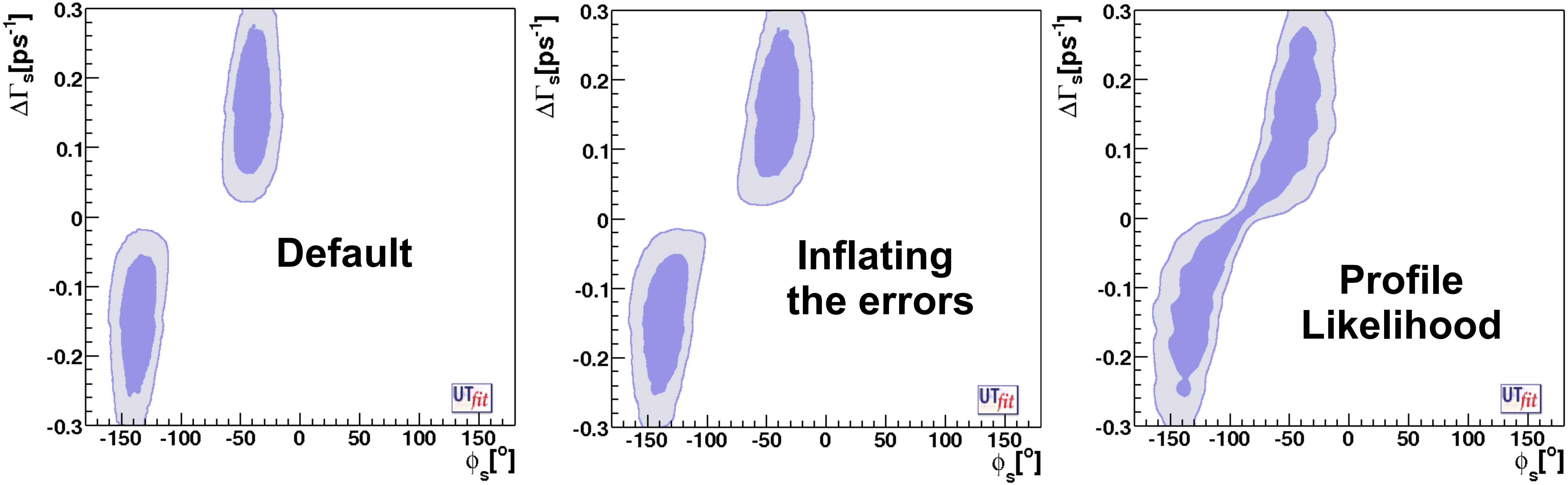
Our analysis (using A_{SL}, A_{CH}, τ_{Bs}, $\Delta\Gamma/\Gamma$)



- **CDF and D0 measurements consider $\Delta\Gamma$ and β_s as uncorrelated parameters**
- **In our analysis, we enforce the dependence of $\Delta\Gamma$ from SM and NP parameters**
- **There is more physics information in our fit than in a simple combination of the two experimental results**

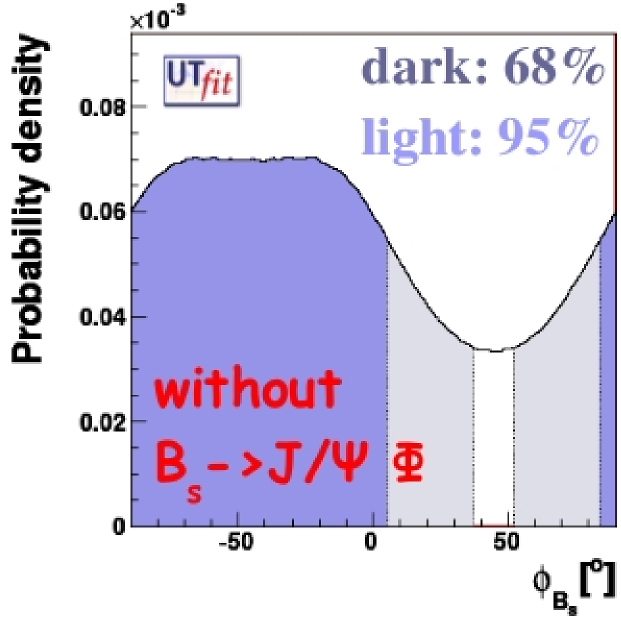
Dependence on the D0 data model

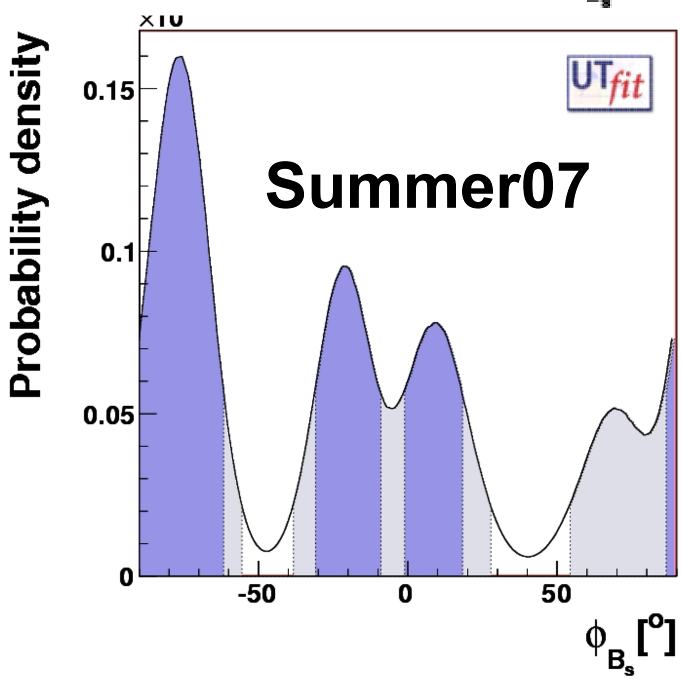
results from all constraints: only the D0 data treatment is changing

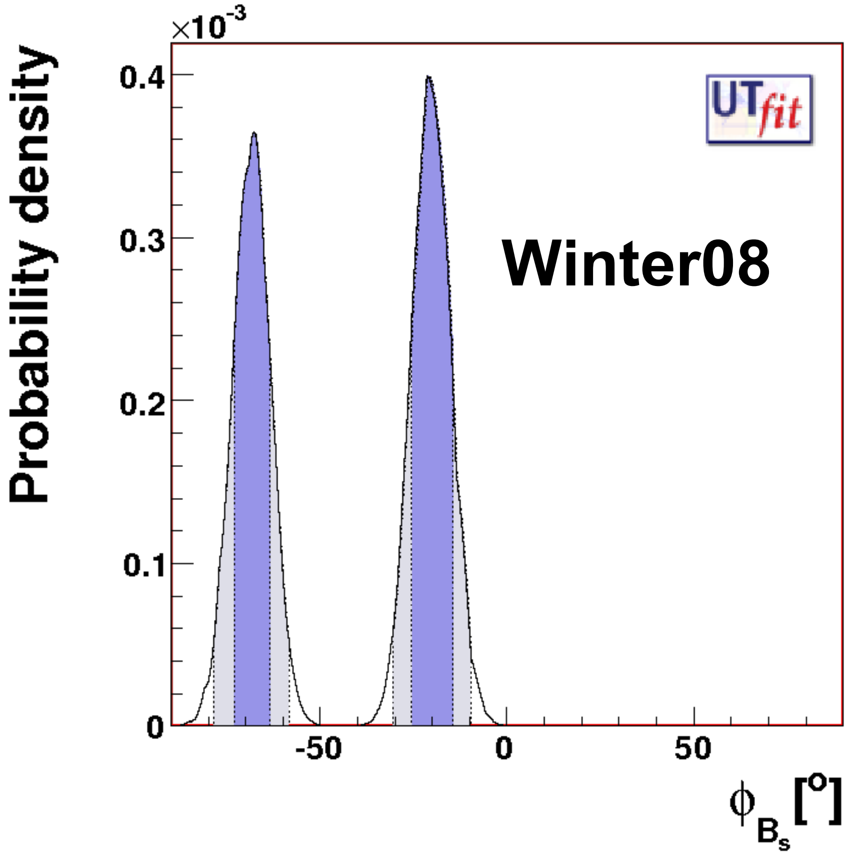


- **The details on how we model D0 are crucial on the side opposite to the SM prediction**
- **The distance from the SM value depends on the approach, but not by O(1) effects**
- **A reduction of the significance is expected when going from the default to the conservative approaches**

Did the result move by a lot?



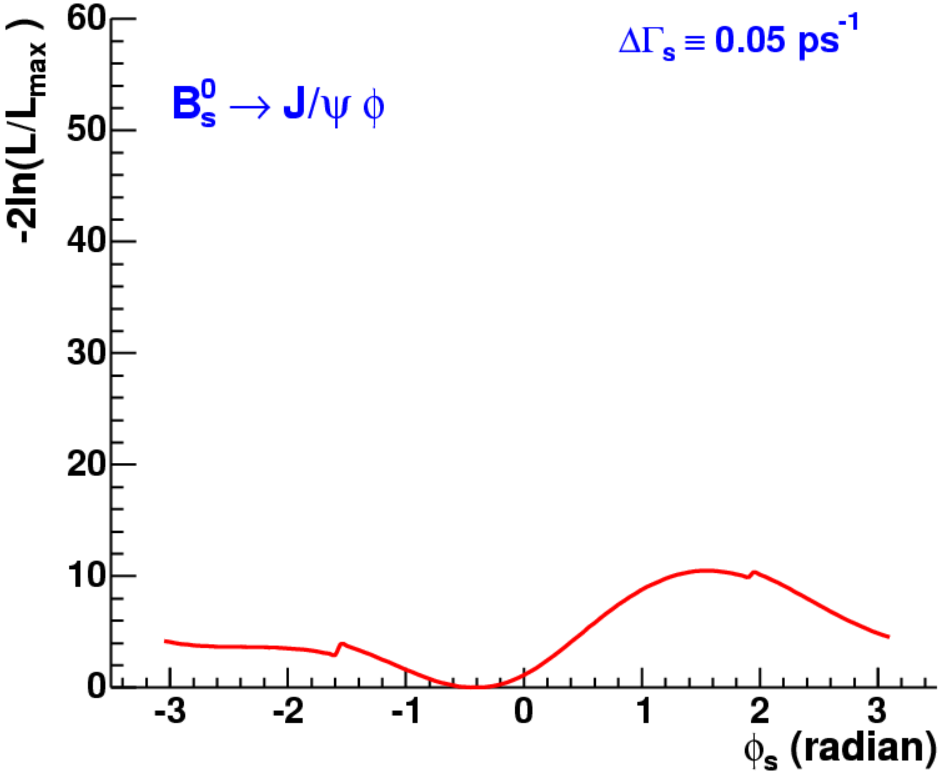


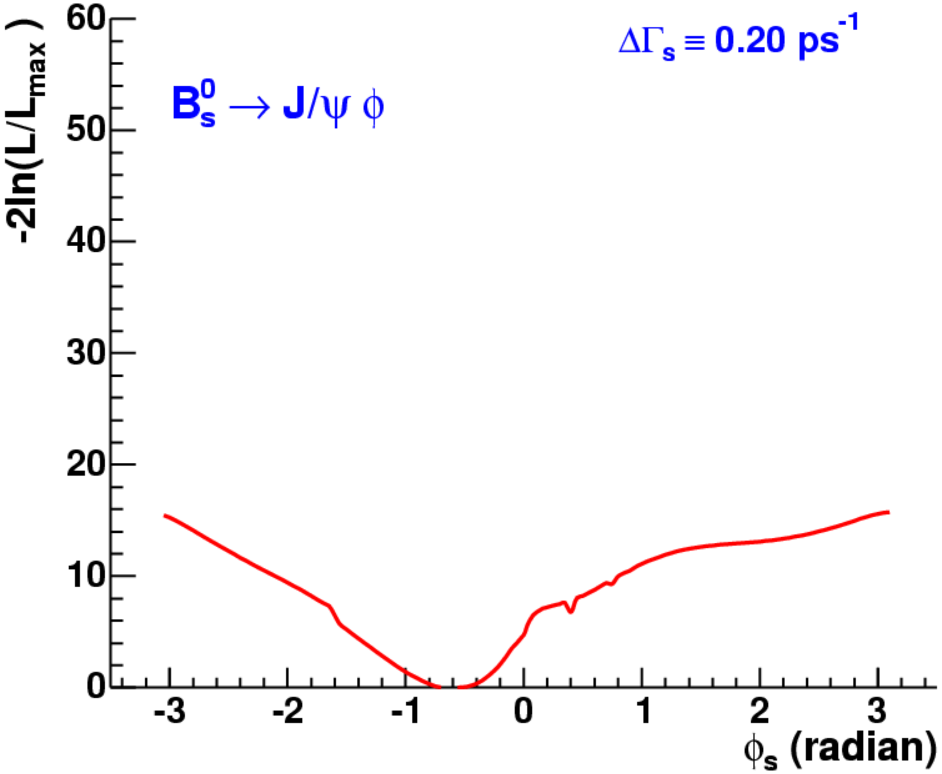


The two most probable peaks last summer are those that survived.

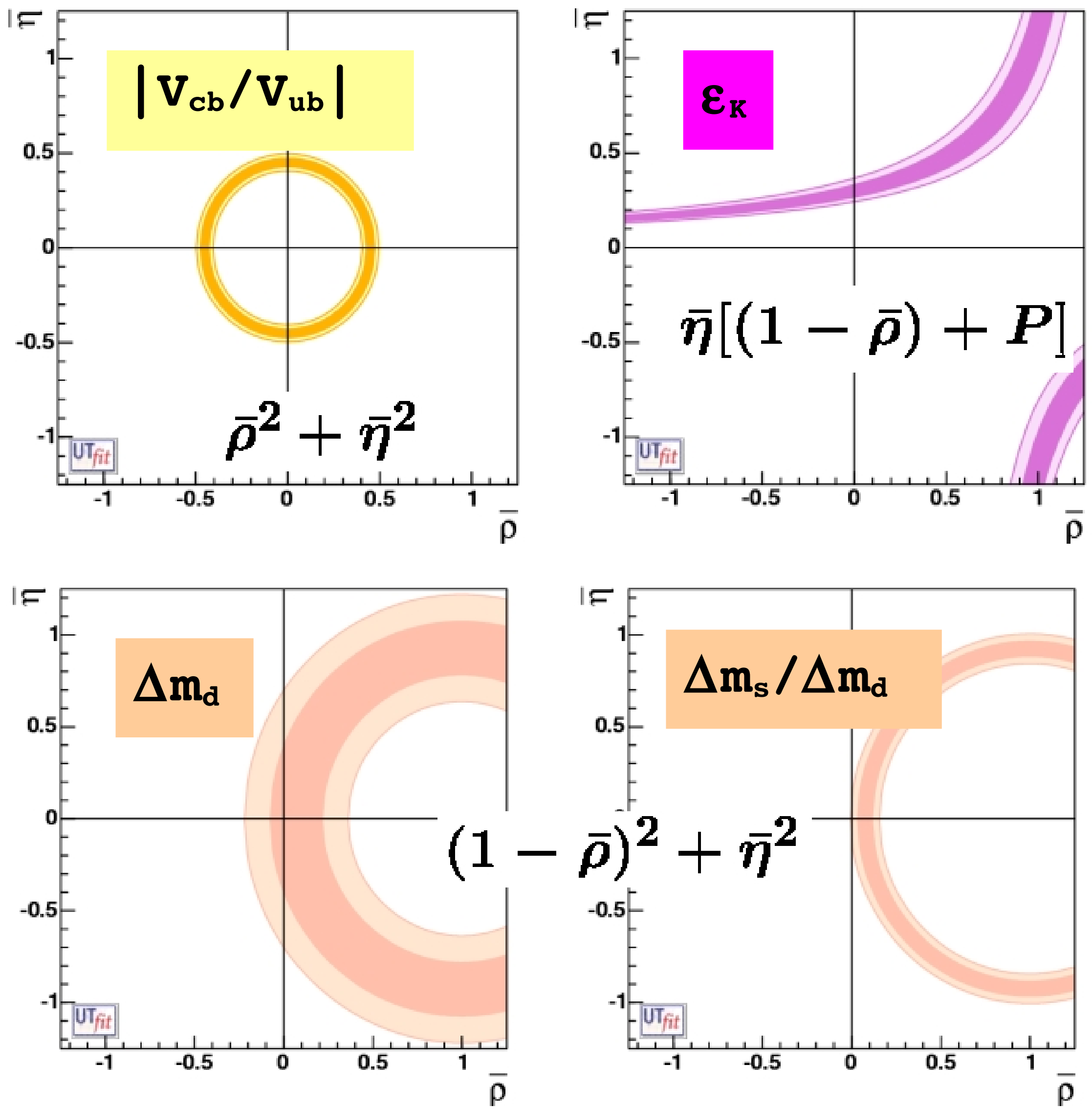
A new 2D likelihood scan from D0

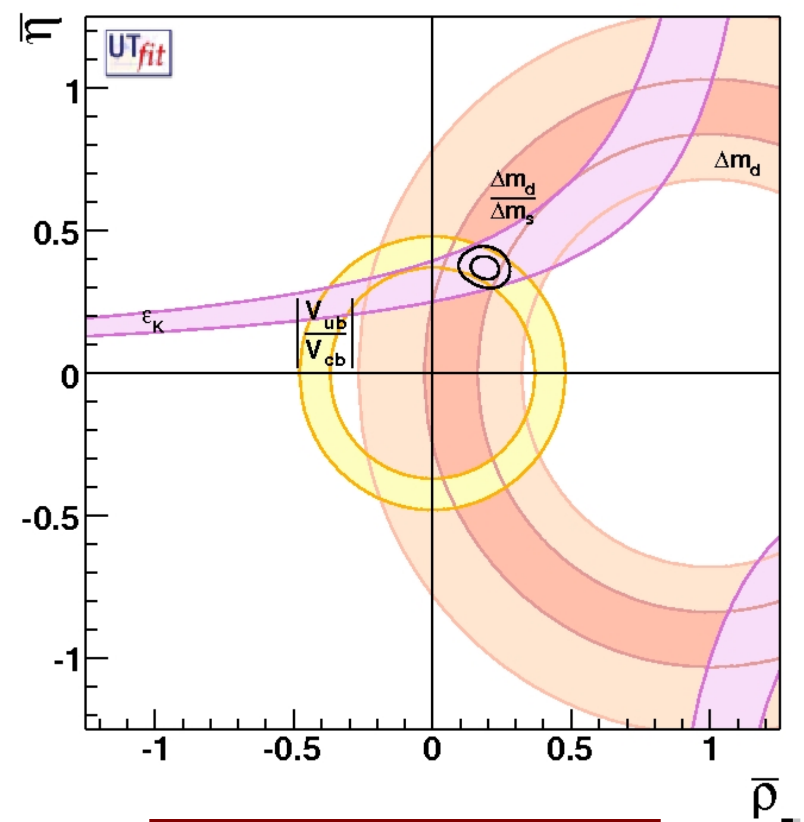
Appeared two weeks ago on the D0 web-site
it hasn't the SU(3) assumption
but the fit looks preliminary:





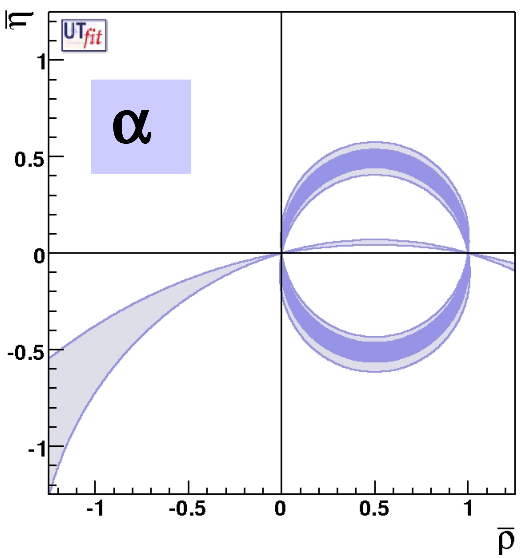
the LEP-style analysis in the $\bar{\rho}$-$\bar{\eta}$ plane:

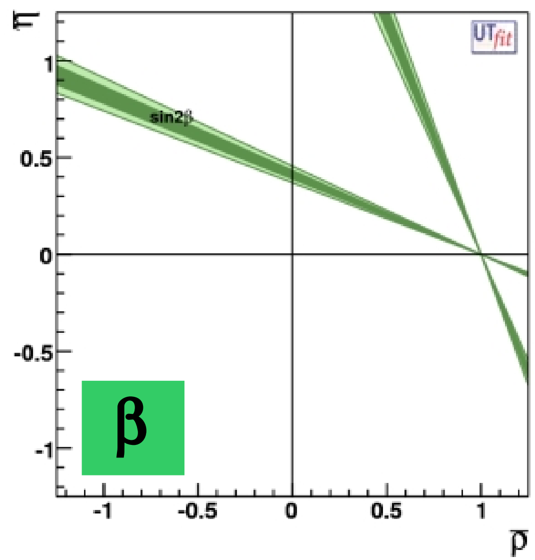


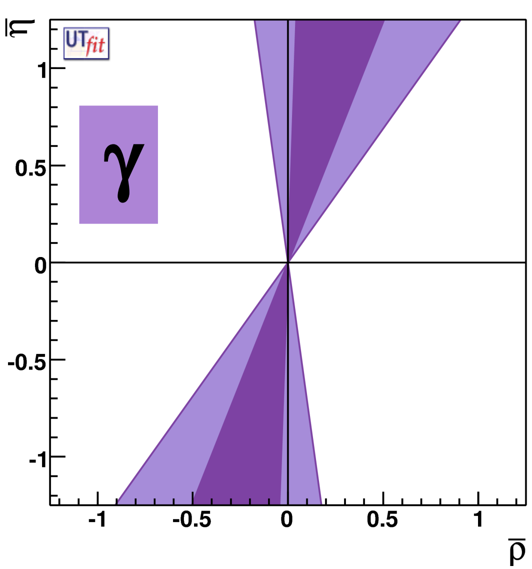


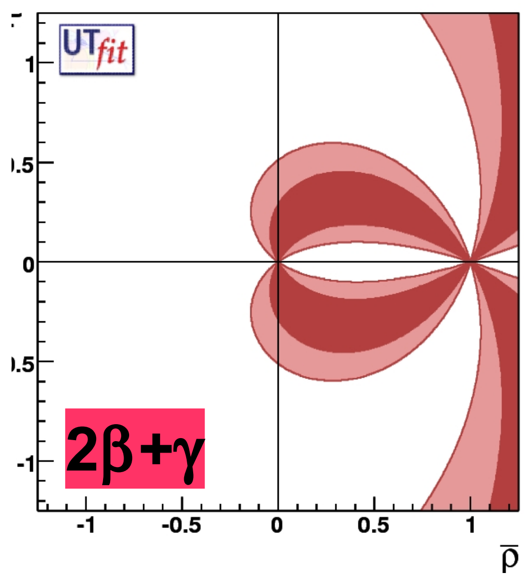
$\bar{\rho}$ = 0.177 ± 0.028
$\bar{\eta}$ = 0.358 ± 0.026

angle constraints in the $\bar{\rho}$-$\bar{\eta}$ plane:

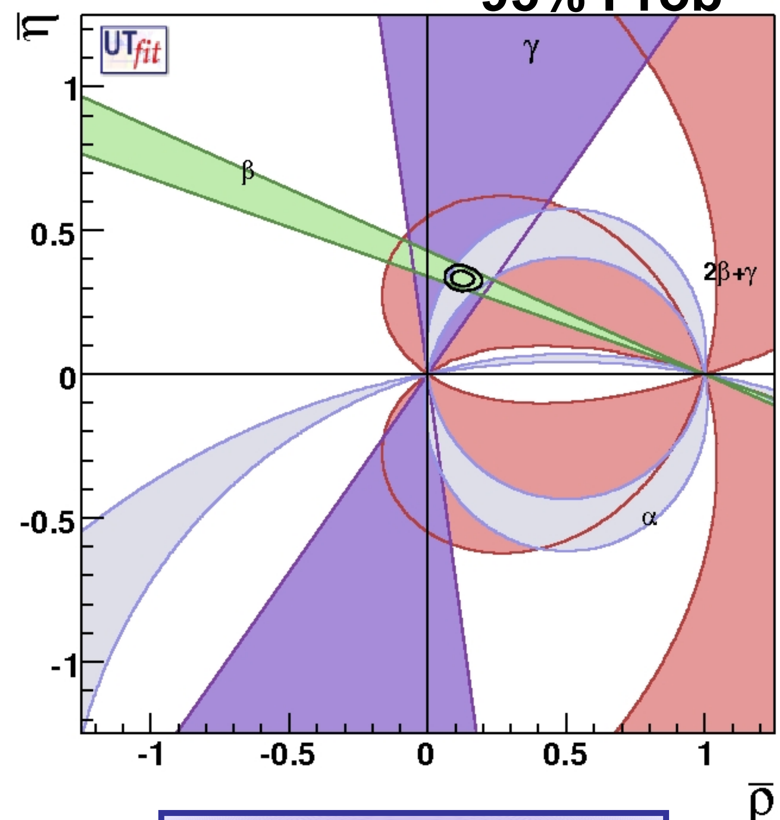








levels @ 95% Prob



$\bar{\rho}$ = 0.126 ± 0.028
$\bar{\eta}$ = 0.332 ± 0.018

Update of the LQCD parameters

Lubicz, Tarantino
for UTfit

$$\hat{B}_K = 0.75 \pm 0.07 ,$$

$$f_{B_s} = 245 \pm 25 \text{ MeV} \quad , \quad f_B = 200 \pm 20 \text{ MeV} \quad , \quad f_{B_s}/f_B = 1.21 \pm 0.04 ,$$

$$f_{B_s}\sqrt{\hat{B}_{B_s}} = 270 \pm 30 \text{ MeV} \quad , \quad f_B\sqrt{\hat{B}_{B_d}} = 225 \pm 25 \text{ MeV} \quad , \quad \xi = 1.21 \pm 0.04 ,$$

$$\hat{B}_{B_d} = \hat{B}_{B_s} = 1.22 \pm 0.12 , \quad \hat{B}_{B_s}/\hat{B}_{B_d} = 1.00 \pm 0.03 ,$$

$$|V_{cb}| \text{ (excl.)} = (39.2 \pm 1.1) \cdot 10^{-3} \quad , \quad |V_{ub}| \text{ (excl.)} = (35.0 \pm 4.0) \cdot 10^{-4} .$$

These averages can be compared with the previous ones used by UTfit

$$\hat{B}_K = 0.79 \pm 0.04 \pm 0.08 ,$$

$$f_{B_s} = 230 \pm 30 \text{ MeV} \quad , \quad f_B = 189 \pm 27 \text{ MeV} \quad , \quad f_{B_s}/f_B = 1.22^{+0.05}_{-0.06} ,$$

$$f_{B_s}\sqrt{\hat{B}_{B_s}} = 262 \pm 35 \text{ MeV} \quad , \quad f_B\sqrt{\hat{B}_{B_d}} = 214 \pm 38 \text{ MeV} \quad , \quad \xi = 1.23 \pm 0.06 ,$$

$$\hat{B}_{B_d} = 1.28 \pm 0.05 \pm 0.09 \quad , \quad \hat{B}_{B_s}/\hat{B}_{B_d} = 1.02 \pm 0.02^{+0.06}_{-0.02} ,$$

$$|V_{cb}| \text{ (excl.)} = (39.1 \pm 0.6 \pm 1.7) \cdot 10^{-3} \quad , \quad |V_{ub}| \text{ (excl.)} = (34.0 \pm 4.0) \cdot 10^{-4} .$$

If this evidence is confirmed...

M.Ciuchini
CERN 08

* MFV models are ruled out, including the simplest realizations of the MSSM
* the following pattern of flavour violation in NP emerges:

  1 <-> 2: strong suppression

  1 <-> 3: $\lesssim O(10\%)$

  2 <-> 3: $O(1)$

  this pattern is not unexpected in flavour models and SUSY-GUTs
* In progress: (i) update of the $\Delta F=2$ operator analysis, (ii) correlations with $\Delta F=1$ in MSSM

$A^{NP}_d/A^{SM}_d \sim 0.1$ and $A^{NP}_s/A^{SM}_s \sim 0.7$ correspond to $A^{NP}_d/A^{NP}_s \sim \lambda^2$ i.e. to an additional λ suppression.

L.Silvestrini
Capri 08

- Lower bounds on NP scale from K and B_d physics: (in TeV at 95% probability)

Scenario	strong/tree	α_s loop	α_W loop
MFV	5.5	0.5	0.2
NMFV	62	6.2	2
General	24000	2400	800

- Upper bounds on NP scale from ϕ_s:

Scenario	strong/tree	α_s loop	α_W loop
NMFV	35	4	2
General	800	80	30

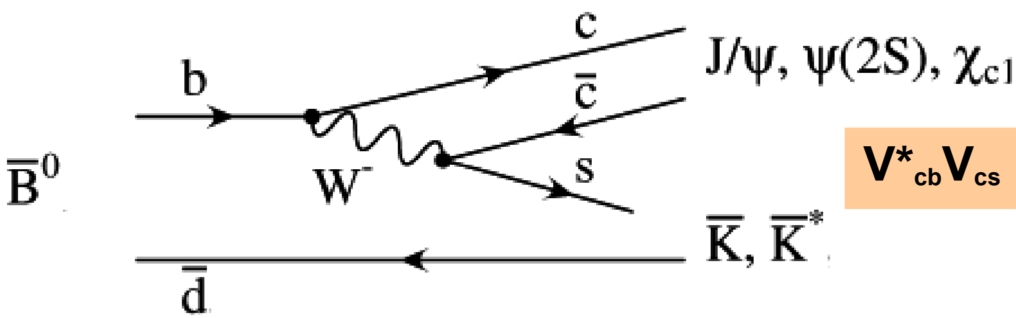
- Need a flavour structure, but not NMFV!

- 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.; …

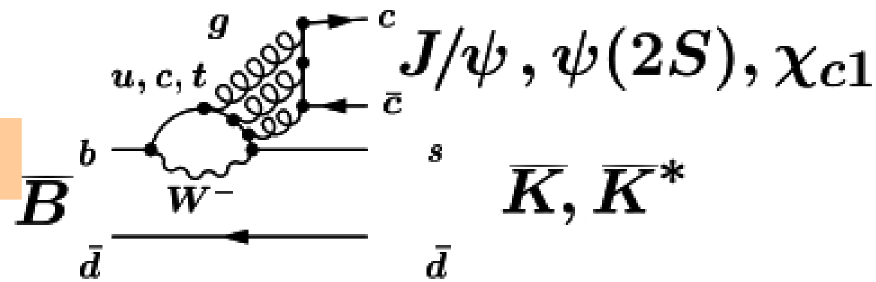
- In a given model expect correlation between $b \leftrightarrow s$ (B_s mixing) and $b \to s$ (penguin decays) transitions
- This correlation is welcome given the large room for NP in $b \to s$ hadronic penguins (S_{peng}, $A_{K\pi}$, …) Beneke; Buchalla et al.; Buras et al.; London et al.; Hou et al.; Lunghi & Soni; Feldmann et al.; …
- The correlation is however affected by large hadronic uncertainties

Silvestrini Capri, 16/6/2008

$\sin 2\beta$ in golden $b \to c\bar{c}s$ modes



$V^*_{cb}V_{cs}$



- **branching fraction: $O(10^{-3})$**
  the colour-suppressed tree dominates and the t penguin has the same weak phase of the tree

$$A_{CP}(t) = \frac{\Gamma(\bar{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\bar{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})} = S \sin \Delta m t - C \cos \Delta m t$$

$S \sim \sin 2\beta$
$C \sim 0$

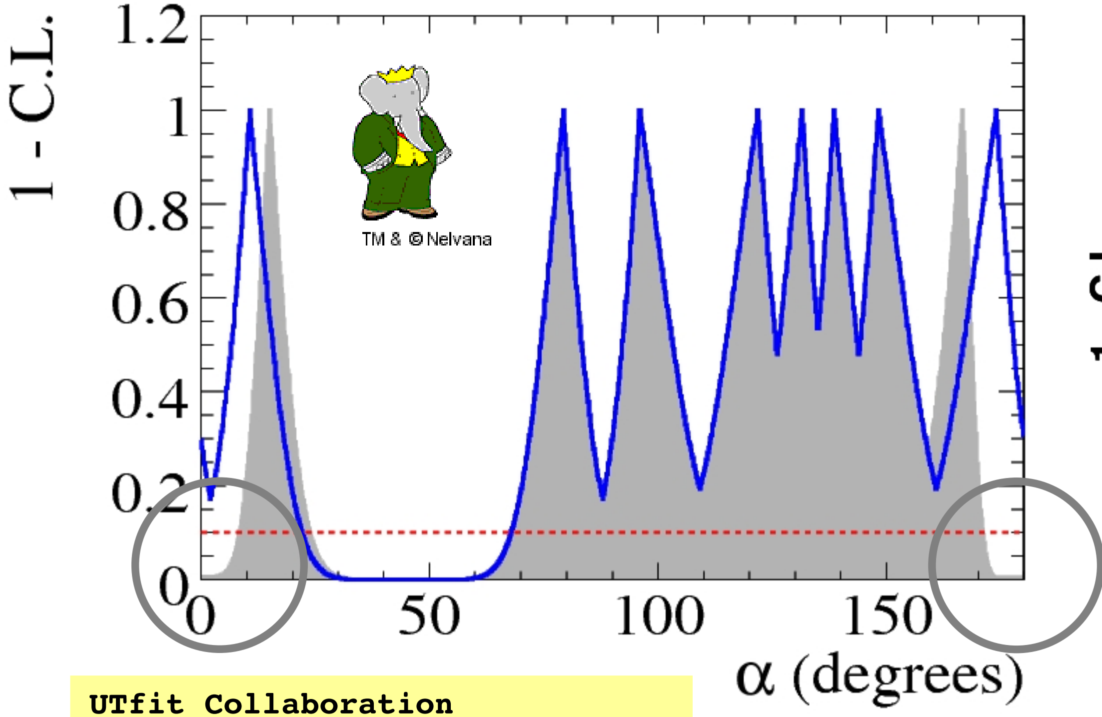
M.Ciuchini, M.Pierini, L.Silvestrini
Phys. Rev. Lett. 95, 221804 (2005)

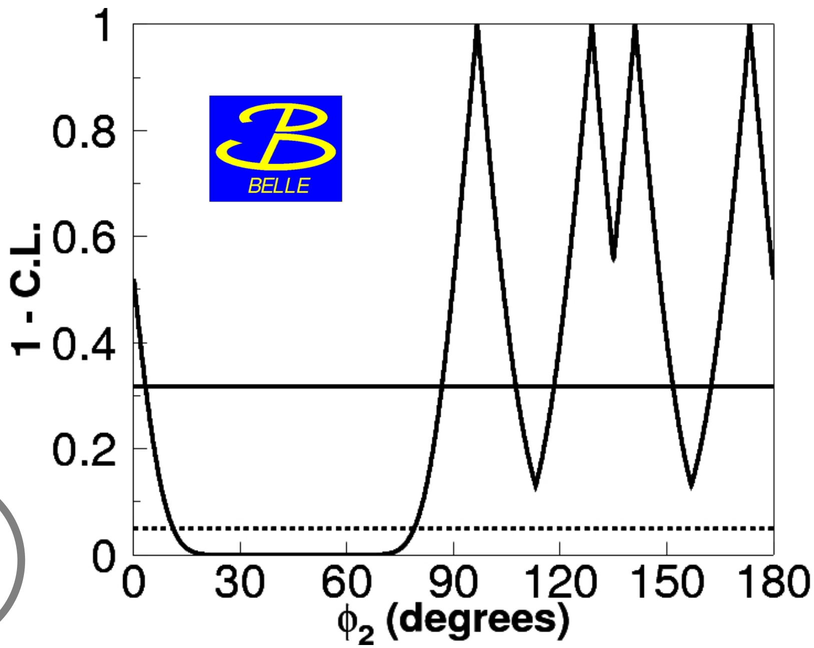
- **theoretical uncertainty:**
  - **model-independent data-driven estimation from $J/\psi\pi^0$ data:**
    $\Delta S_{J/\psi K0} = S_{J/\psi K0} - \sin 2\beta = 0.000 \pm 0.012$
  - **model-dependent estimates of the u- and c- penguin biases**
    $\Delta S_{J/\psi K0} = S_{J/\psi K0} - \sin 2\beta \sim O(10^{-3})$
    $\Delta S_{J/\psi K0} = S_{J/\psi K0} - \sin 2\beta \sim O(10^{-4})$

H.Li, S.Mishima
JHEP 0703:009 (2007)

H.Boos et al.
Phys. Rev. D73, 036006 (2006)

At last: α from $\pi\pi$ decays





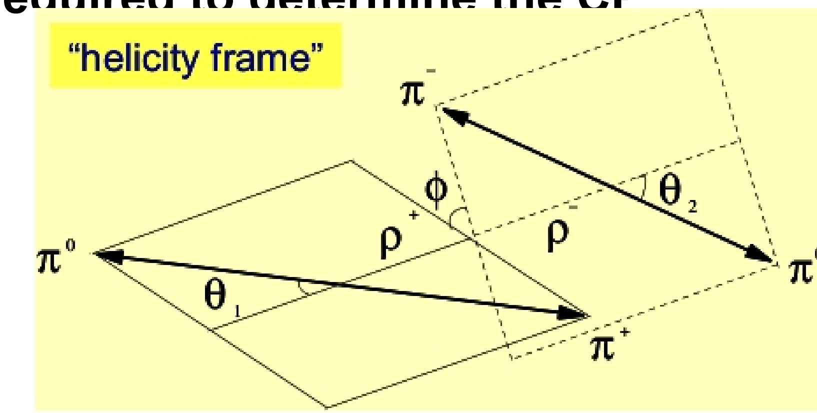
UTfit Collaboration
Phys.Rev.D76:014015(2007)

BaBar: 25° < α < 66° excluded @ 90% CL

Belle: 11° < α < 79° excluded @ 95% CL

But there is more: α from $\rho\rho$ decays

- Vector-Vector modes: angular analysis required to determine the CP content. L=0,1,2 partial waves:
  - longitudinal: CP-even state
  - transverse: mixed CP states
- +-: two π^0 in the final state
- wide ρ resonance

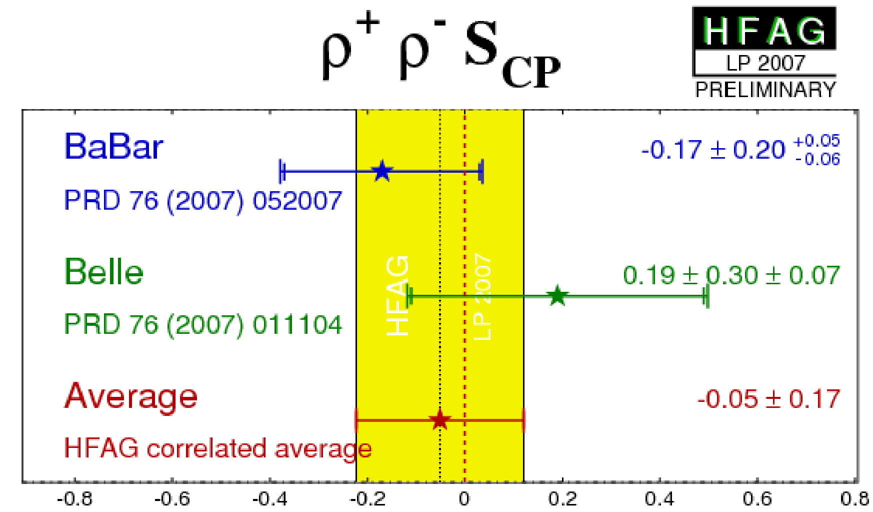


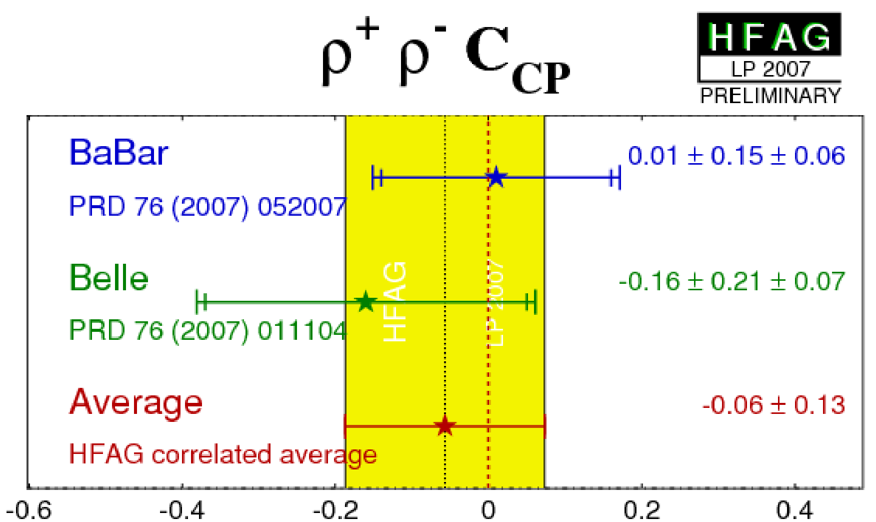
but

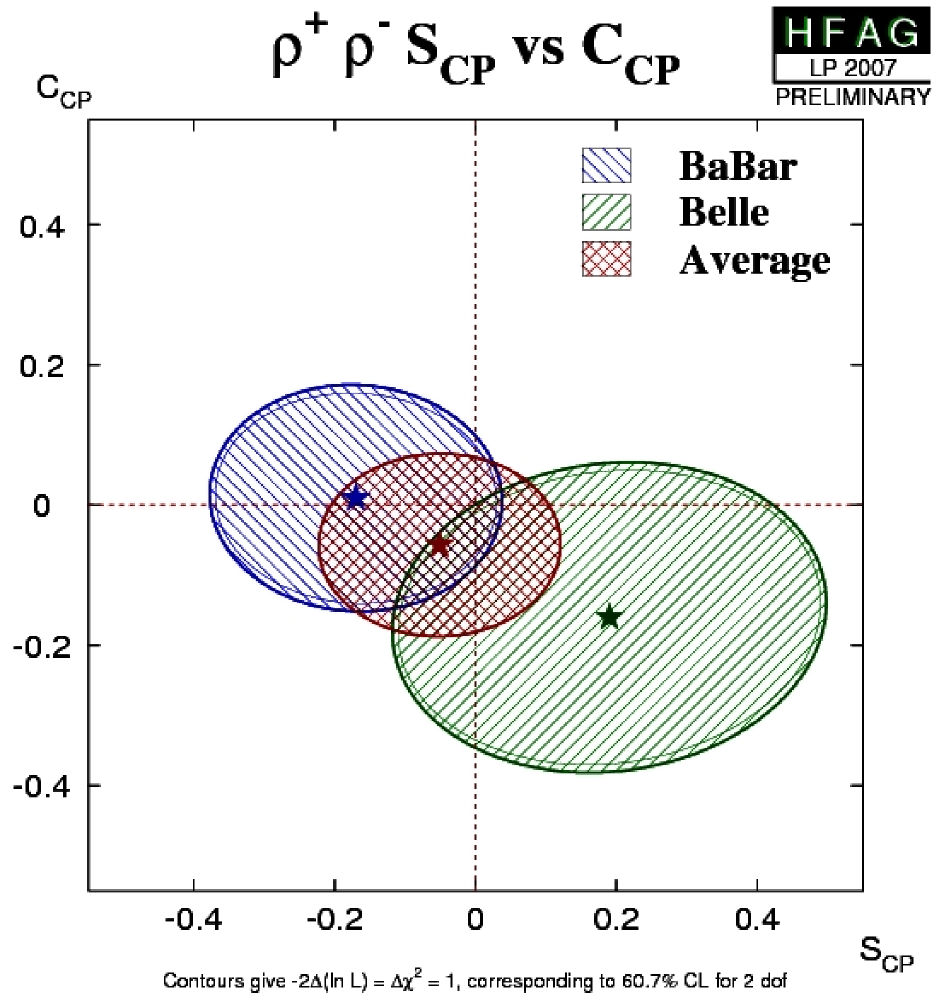
- BR 5 times larger with respect to $\pi\pi$
- penguin pollution might be smaller than in $\pi\pi$
- ρ are almost 100% polarized:
  - almost a pure CP-even state

- world average longitudinal fraction:
  - $f_{long}\,(\rho^+\rho^-) = 0.978 \pm 0.025$
  - $f_{long}\,(\rho^\pm\rho^0) = 0.912 \pm 0.045$
  - $f_{long}\,(\rho^0\rho^0)$ still to be measured

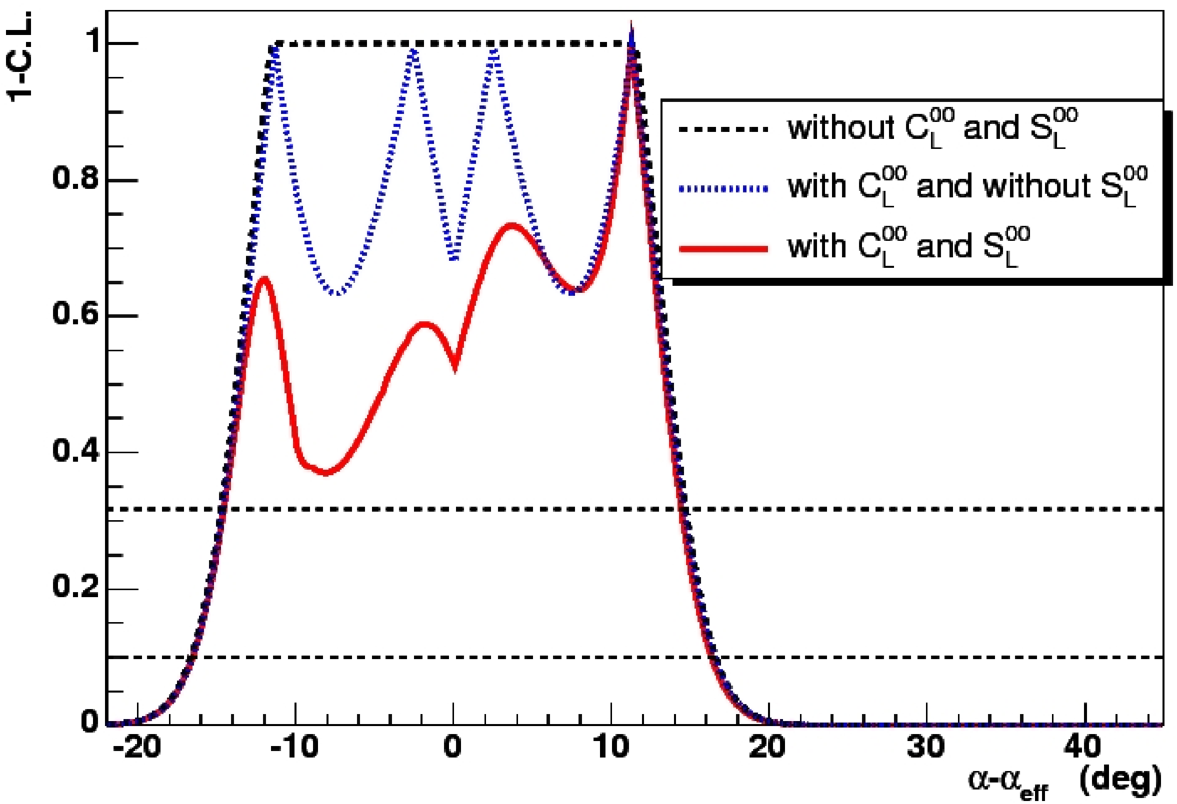
World averages in $\rho^+\rho^-$ decays

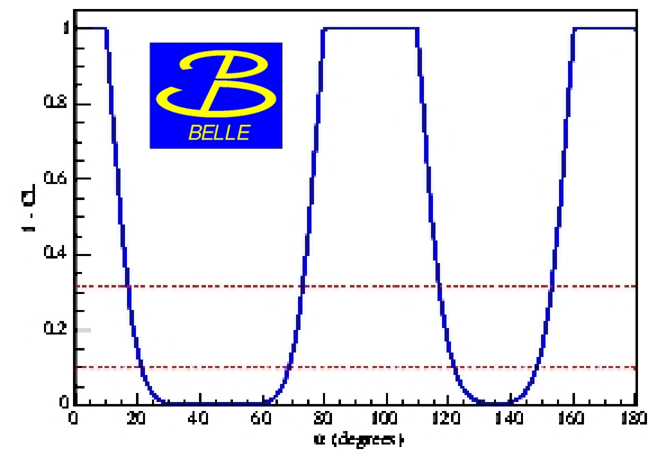






Preliminary ρρ isospin analysis

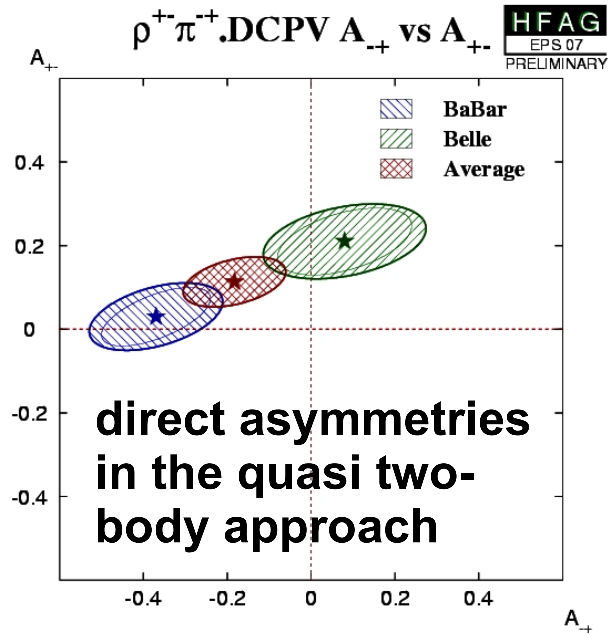




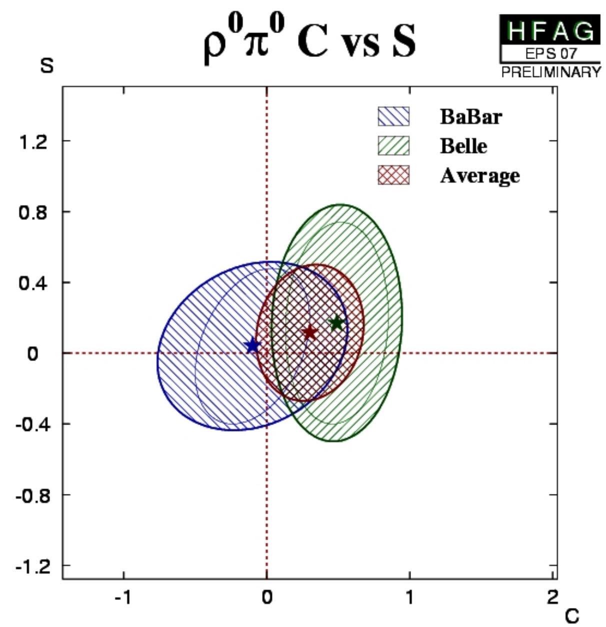
using BaBar $\rho^0\rho^0$:
$|\alpha - \alpha_{eff}| < 16.5°$ @ 90% CL

in ππ :
$|\alpha - \alpha_{eff}| < 39°$ @ 90% CL

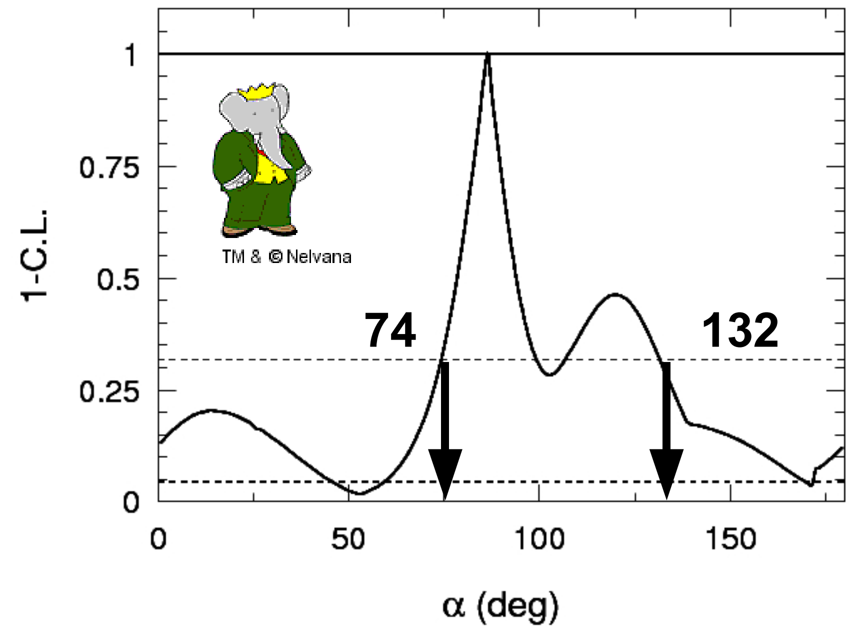
Results from $(\rho\pi)^0$

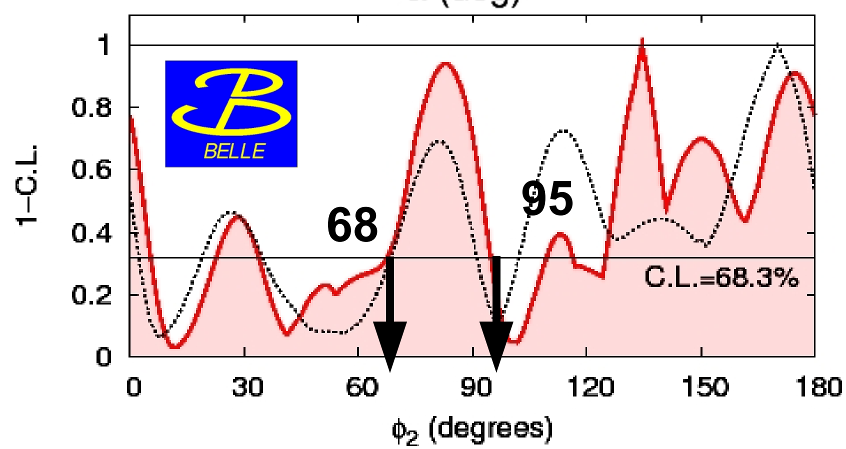


direct asymmetries in the quasi two-body approach



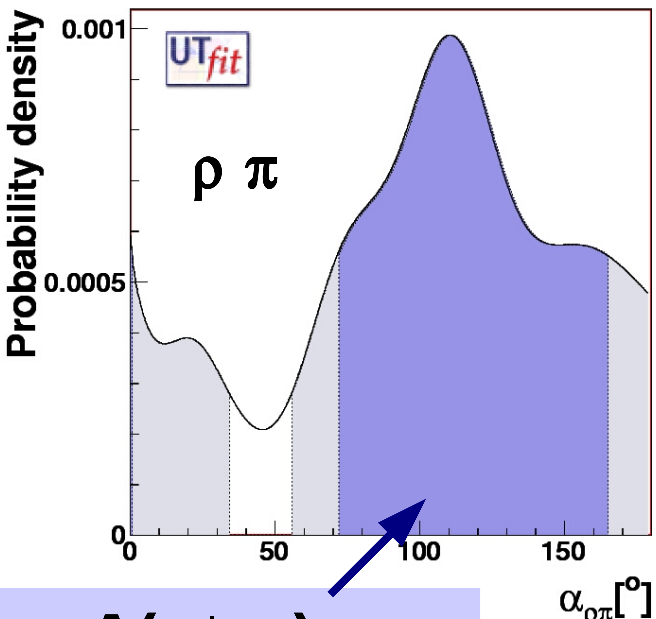
- **this analysis allows for a direct determination of α without ambiguities**

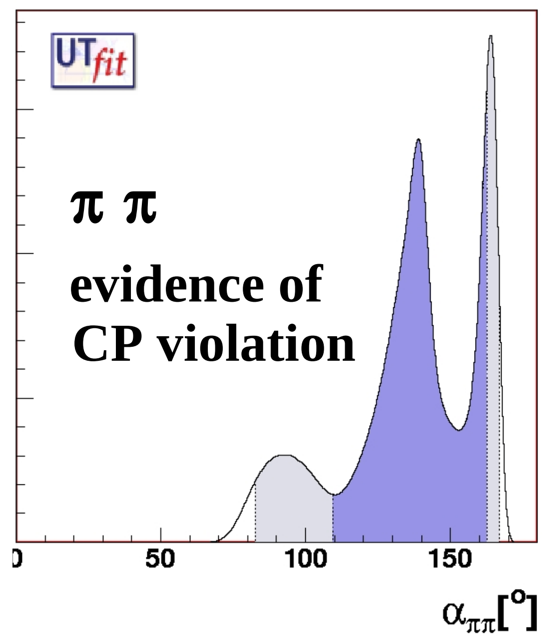


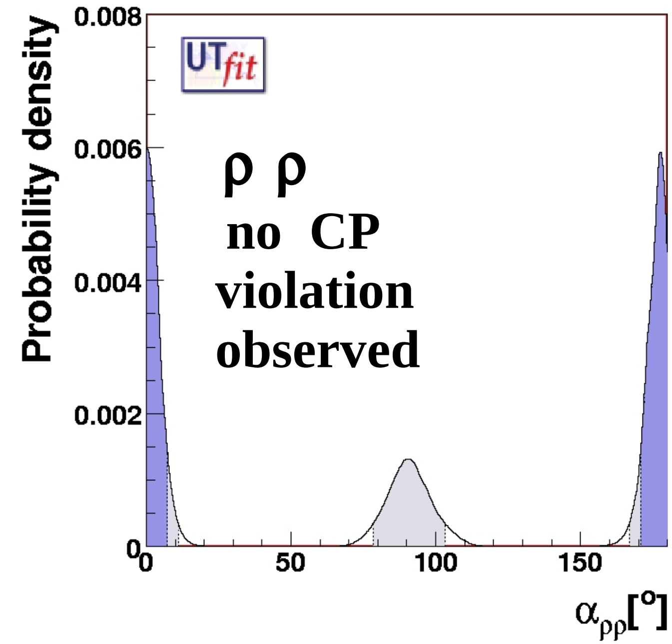


no values excluded, no values selected *yet*

α extraction from the three analyses



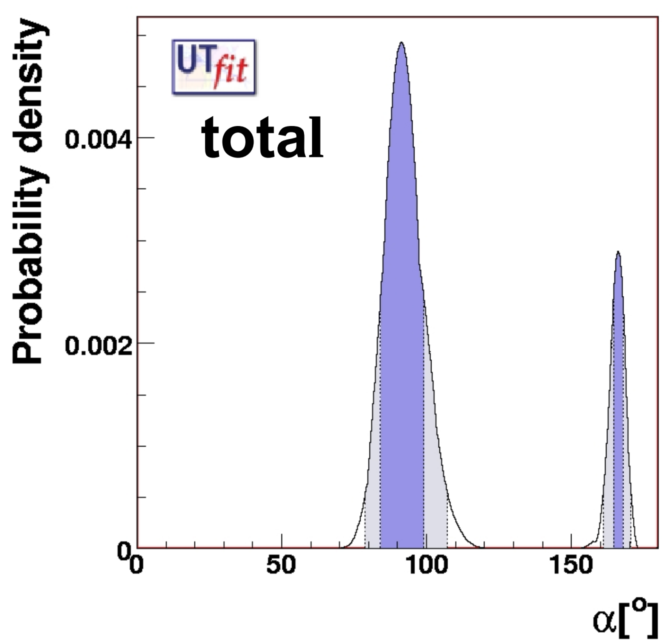


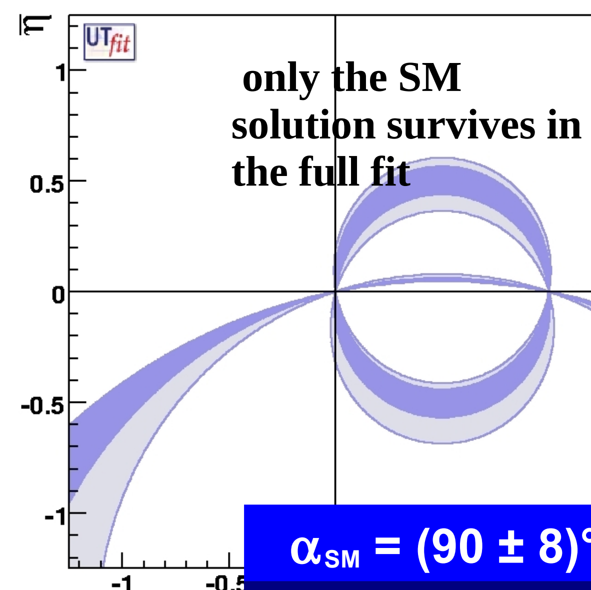


$$A = A(\rho^+\pi^-) + A(\rho^-\pi^+) + 2A(\rho^0\pi^0) = (T^{+-} + T^{-+} + 2T^{00})\, e^{2i\alpha}$$

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

no parameterization involved





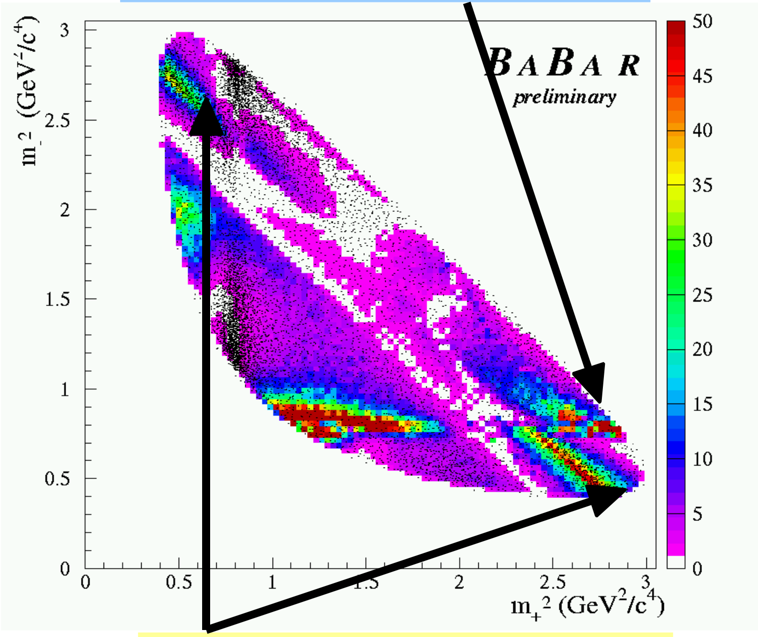
$\alpha_{SM} = (90 \pm 8)°$

$\alpha_{UTfit} = (92 \pm 4)°$

γ measurement: Dalitz method

- neutral D mesons reconstructed in three-body CP-eigenstate final states (typically $D^0 \to K_S\pi^-\pi^+$)
- the complete structure (amplitude and strong phases) of the D^0 decay in the phase space is obtained on independent data sets and used as input to the analysis
- use of the cartesian coordinate:
  - $x_\pm = r_B \cos(\delta \pm \gamma)$
  - $y_\pm = r_B \sin(\delta \pm \gamma)$
- γ , r_B and δ_B are obtained from a simultaneous fit of the $K_S\pi^+\pi^-$ Dalitz plot density for B^+ and B^-
- need a model for the Dalitz amplitudes
- 2-fold ambiguity on γ

Interference of
$B^- \to D^0K^-$, $D^0 \to K^{*+}\pi^-$
(suppressed) with
$B^- \to \overline{D}{}^0K^-$, $\overline{D}{}^0 \to K^{*+}\pi^-$
~ ADS like



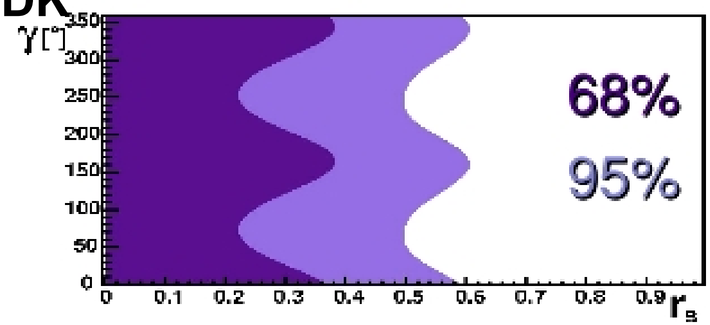
Interference of
$B^- \to D^0K^-$, $D^0 \to K^0_S\rho^0$
with
$B^- \to \overline{D}{}^0K^-$, $\overline{D}{}^0 \to K^0_S\rho^0$
~ GLW like

More ways to γ

- with neutral B's in the final states D^0K^{*0} with $D^0 \to K_S\pi^-\pi^+$ and $K^* \to K^-\pi^+$,
  - the charge of the K from the K* tags the flavour of the B^0 so no time-dependent analysis
  - first analysis to extract γ from neutral $B \to DK$
  - BaBar performed it with 371M $\bar{B}B$

    $\gamma = (162 \pm 56)°$ (mod.180°)

    r_s (D^0K^{*0}) < 0.55 @ 95% Prob.



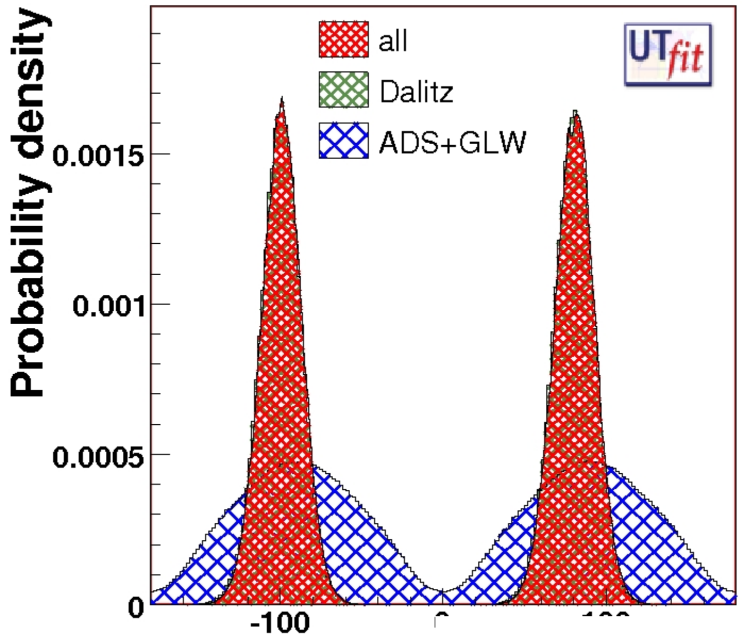
- again with neutral B's, time-dependent Dalitz plot analysis of the three-body final state $B^0 \to D^-K^0\pi^+$
  - interference between $b \to u$ and $b \to c$ transitions through the mixing: sensitivity to $2\beta+\gamma$
  - BaBar performed it with 347M $\bar{B}B$

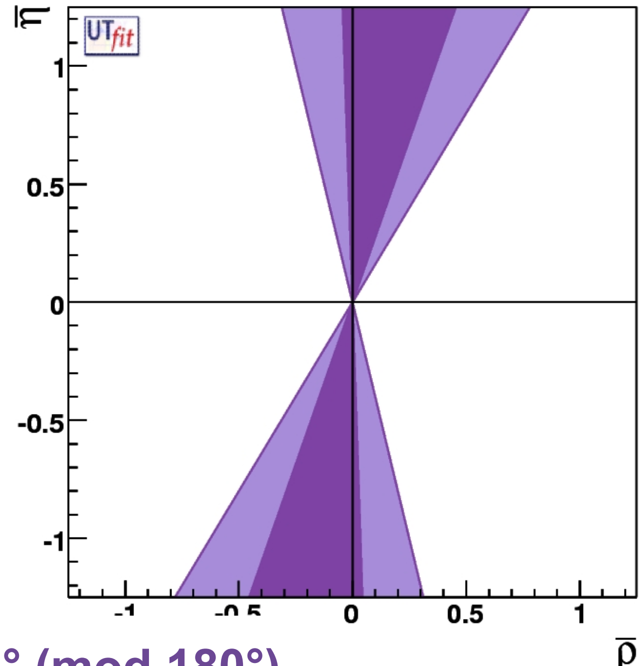
    $2\beta+\gamma = (83 \pm 53 \pm 20)°$ (mod.180°)

Dalitz method: carthesian coordinates

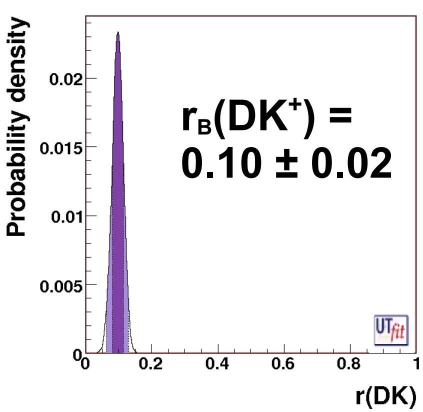
- from previous studies, we know that (γ , δ_B and r_B) are **not** a good choice from the fit point of view
  - no sensitivity to γ if $r_B < 0.10$ (underestimation of the errors)
  - fit bias on r_B for $r_B \sim 0.10$ (physical bound + low statistics)
- fit for cartesian coordinates instead: $x_{\pm}$, $y_{\pm}$
  - $x_{\pm} = \mathrm{Re}[r_B\, e^{i(\delta \pm \gamma)}]$, $y_{\pm} = \mathrm{Im}[r_B\, e^{i(\delta \pm \gamma)}]$
  - gaussian errors: no unphysical zones
  - (x+, y+), (x-, y-) uncorrelated
  - unbiased results for all possible r_B
- also in the GLW:
  - $x_{\pm} = [R_{CP+}(1 \mp A_{CP+}) - R_{CP-}(1 \mp A_{CP-})]/4$

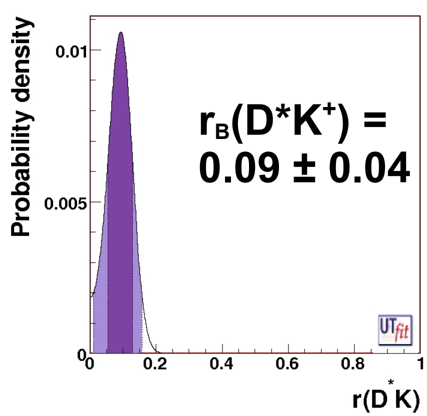
Combining the methods for γ

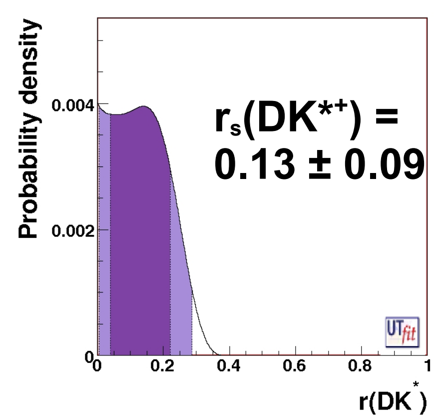




$\gamma = (80 \pm 13)°$ (mod.180°)







the method and the inputs:

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

Bayes Theorem

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

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

$(b\to u)/(b\to c)$	$\bar\rho^2+\bar\eta^2$	$\bar\Lambda, \lambda_1, F(1), \ldots$
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
$A_{CP}(J/\psi K_S)$	$\sin 2\beta$	

, **mt**

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

M. Bona *et al*. (UTfit Collaboration) JHEP 0507:028,2005 hep-ph/0501199
M. Bona *et al*. (UTfit Collaboration) JHEP 0603:080,2006 hep-ph/0509219

Gronau-London method:

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

$A^{00} = 1/\sqrt{2}\,(e^{-i\alpha}\, T^{00} - P)$

$A^{+0} = 1/\sqrt{2}\, e^{-i\alpha}\,(T^{+-} + T^{00})$

CP: $\alpha \rightarrow -\alpha$

6 parameters: $|T^{+-}|$, $|T^{00}|$, $|P|$, δ^{00}, δ^{P}, α

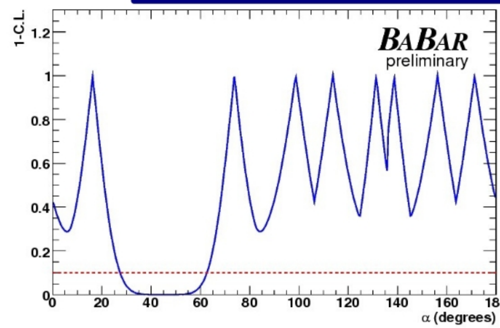
6 observables: B^{+-}, B^{00}, B^{+0}, C^{+-}, S^{+-}, C^{00}

$$B^{+-,00}_{\pi\pi} = \frac{1}{2}\left(\left|A^{+-,00}\right|^2 + \left|\bar{A}^{+-,00}\right|^2\right) \quad , \quad B^{+0}_{\pi\pi} = \frac{\tau_{B^+}}{\tau_{B^0}}\frac{1}{2}\left(\left|A^{+0}\right|^2 + \left|\bar{A}^{+0}\right|^2\right)$$

$$C^{ij}_{\pi\pi} = \frac{\left|A^{ij}\right|^2 - \left|\bar{A}^{ij}\right|^2}{\left|A^{ij}\right|^2 + \left|\bar{A}^{ij}\right|^2} \quad , \quad S^{ij}_{\pi\pi} = \frac{\mathrm{Im}\ A^{ij}\bar{A}^{ij*}}{\left|A^{ij}\right|^2 + \left|\bar{A}^{ij}\right|^2}$$

8 or 0 solutions

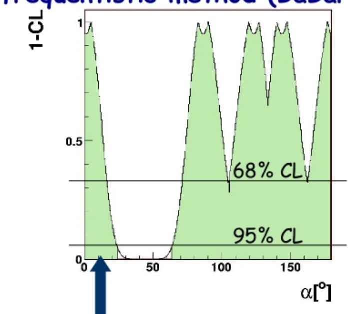
interpretation of the results



frequentistic method (BaBar paper)

"some of the solutions, and the region around a=0 can be disfavoured by other physics information"

frequentistic method (BaBar+Belle)



The region around α =0 is not excluded, despite the experimental observation of CP violation.

what kind of "other information"?

The GL method already requires some a priori "minimal assumptions" on strong interactions, namely:
- Flavour blind and CP conserving strong interactions
- Negligible isospin symmetry breaking effects, including e.m. corrections

This is because we believe that:
- QCD is the theory of strong interactions
- QCD is a renormalizable theory with a dimensionless coupling constant and a natural scale Λ_{QCD} ~ 1 GeV

$\langle M_1 M_2 | O | M \rangle \sim (\Lambda_{QCD})^3$ case of a single scale

Therefore we do not expect: $\langle \pi\pi | O | B \rangle \sim$ (1 TeV)³ or $(M_{Planck})^3$

scales and dimensions

In our case: two scales enter in the process, M_B and Λ_{QCD}

so we expect: $\langle \pi\pi|\hat{O}|B\rangle \sim f_\pi M_B^2 f^+(0) \sim f_\pi M_B^2 \left(\frac{\Lambda_{QCD}}{M_B}\right)^{3/2} \sim M_B^{1/2}\Lambda_{QCD}^{5/2}$

Note: the scaling law has a more general validity than factorization

- This gives: $T^{ij} \sim 1$ [We use "natural units": the BR x 10⁶ are simply given by the squared amplitude]

But we can think of other considerations:
- using strict factorization

$$|T^{+-}|^2 = \frac{G_F^2 \tau_B |V_{ub}V_{ud}^*|^2}{32\pi M_B} |C_1(M_B)\langle\pi^+\pi^-|O_1|B_d^0\rangle + C_2(M_B)\langle\pi^+\pi^-|O_2|B_d^0\rangle|^2 \times 10^6$$
$$= \frac{G_F^2 \tau_B |V_{ub}V_{ud}^*|^2}{32\pi M_B} \left|\frac{C_1(M_B)}{3} + C_2(M_B)\right|^2 \times |M_B^2 f_\pi f^+(0)|^2 \times 10^6$$

- This gives: $|T^{+-}| = 3.2$

several theoretical predictions exist(ed)

[17] Ciuchini et al.'98
[18] BBNS'99
[19] Keum et al.'02

$BR(\pi^+\pi^0)$

ref. [17]	ref. [18]	ref. [19]	Exp.
3.6 – 5.3	4.3 (1 ± 0.3)	$3.7^{+1.3}_{-1.1}$	5.5 ± 0.6

further considerations

- scaling between B and D decays

In the heavy quark limit, the dependence on M_H cancels in the decay rate.

$$R = \frac{|T^{+-}(B^0_d \to \pi^+\pi^-)|^2}{|T^{+-}(D^0 \to \pi^+\pi^-)|^2} \sim \frac{|V_{ub}V^*_{ud}|^2}{|V_{cd}V^*_{ud}|^2}$$

$$|T^{+-}|^2 = BR(D^0 \to \pi^+\pi^-) \times 10^6 \frac{\tau_{B^0_d}}{\tau_{D^0}} R$$

➜ This gives: $|T^{+-}| = 1.3$

- extract P from the $B_s \to K^+K^-$ decay

Up to DCS terms

$$|P|^2 = BR(B_s \to K^+K^-) \times 10^6 \frac{\tau_{B^0_d}}{\tau_{B^0_s}} \frac{|V_{td}V^*_{tb}|^2}{|V_{ts}V^*_{tb}|^2} \; : \; |P_s|^2 \overset{SU(3)}{=} |P|^2$$

$|P_s| = 1.1$ → (SU(3)) → $|P| \leq 2.5$ → ($\pi\pi$) → $|T^{+-}| \approx 1$

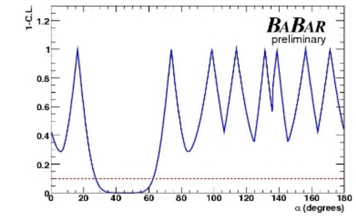
assuming that SU(3) breaking effects are not larger than 100%

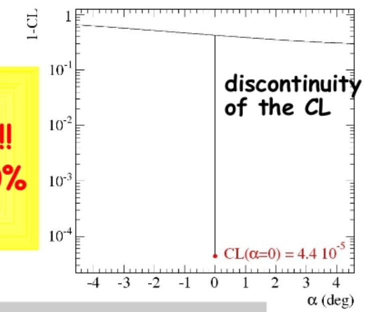
some consequences

- solution for $\alpha \to 0$

in order to reproduce the experimental values of BR($\pi^+\pi^-$) and BR($\pi^0\pi^0$) we may have |T|>>1 and |P|>>1, but |T| ~ |P|

$\alpha < 2° \to |T^{+-}| > 30$
$\to |P| \sim 30 \to$ SU(3) breaking~3000% !!
$\to m_s/m_d \sim 10 \to$ SU(2) breaking~300%
(Gronau-London??)





the results are contradicting the assumptions

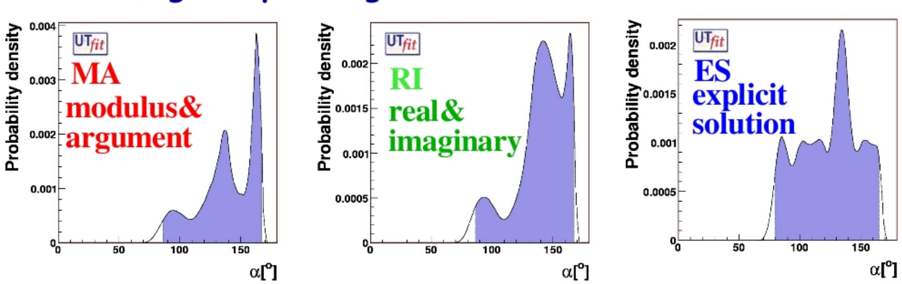
using the available information (priors)

In previous UTfit analyses: $|T^{ij}| \leq 10$, $|P| \leq 10$

Now: $|T^{ij}| \leq 10$, $|P| \leq 2.5$, arbitrary phases ← SU(3) breaking ≤ 100%

$|T^{ij}|$ will be automatically limited

1) The information on the matrix elements has the effect of eliminating some of the eight solutions, including the pathological solution at $\alpha \sim 0$

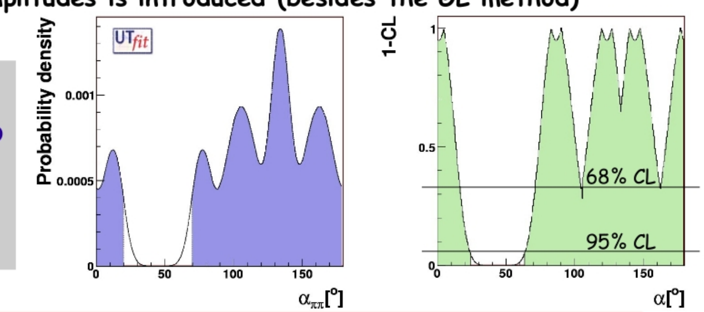


Bayesian vs Frequentistic analysis

Compare the 2 methods using the same assumptions

- In the Bayesian approach: extract BR's and CP parameters with gaussian p.d.f. according with their experimental values and errors
- In the frequentistic analysis: no additional information on the hadronic amplitudes is introduced (besides the GL method)

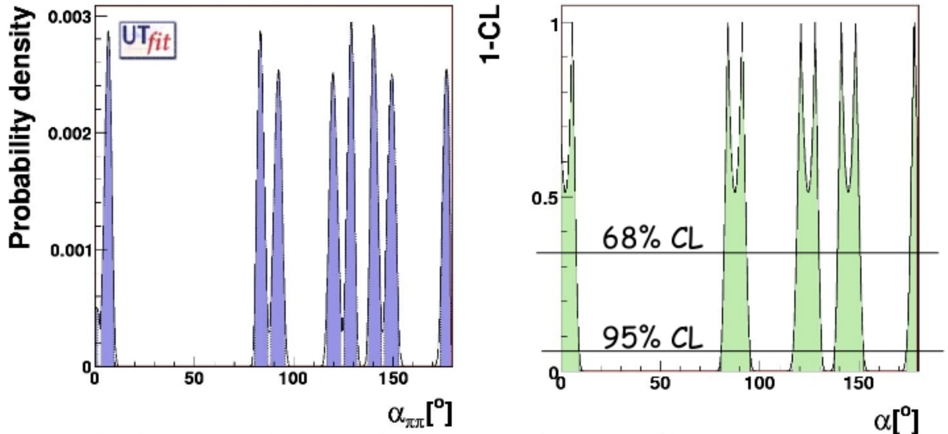
Caveat: these are two different quantities: p.d.f. or CL



The two approaches give equivalent results at a meaningful CL/Prob.

further comparison:

Reducing the experimental errors by
a factor of 10 at fixed central values

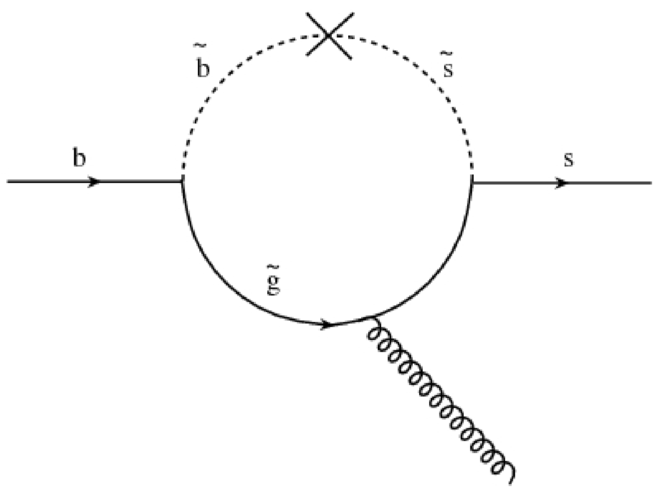


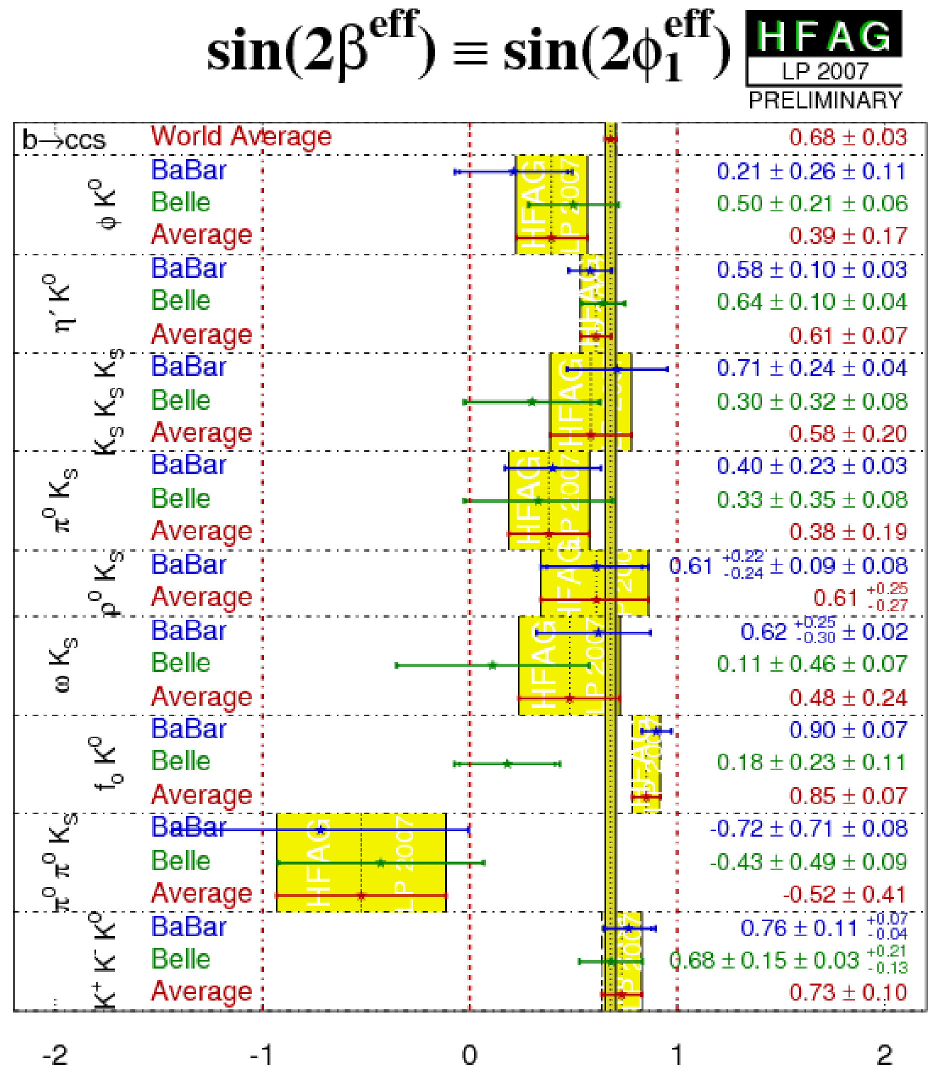
Not yet really separated at a meaningful CL

The eight solutions "start" to be separated both in the Bayesian and frequentistic case

Provided the same assumptions are done, the two approaches lead to similar results

b → s penguins





- **Extra sources of FCNC: investigation looking at b ↔ s penguin decays**
- **Some "hints" seen on sin2β in penguin decays**
- **Difficult interpretation due to theoretical issues (but SM hadron corrections are expected to induce positive shifts)**

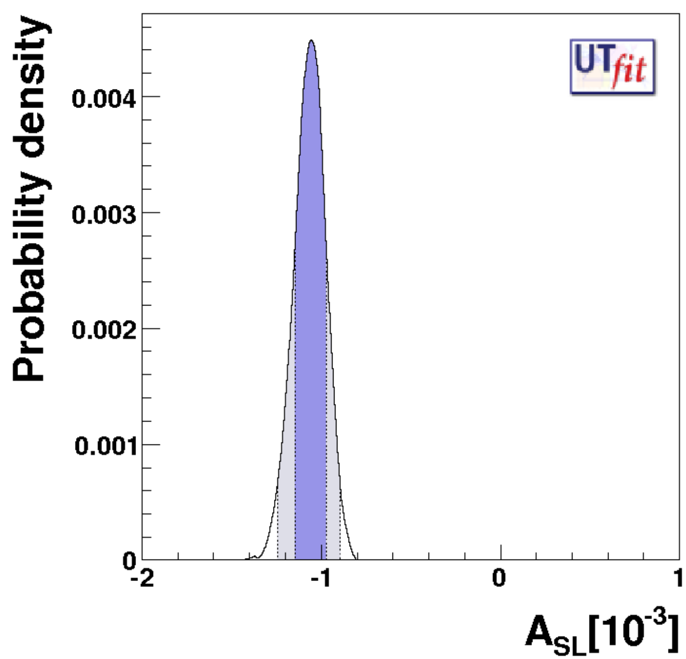
Semileptonic Asymmetry A_{SL}

$$A_{\rm SL} \equiv \frac{\Gamma(\bar{B}^0 \to \ell^+ X) - \Gamma(B^0 \to \ell^- X)}{\Gamma(\bar{B}^0 \to \ell^+ X) + \Gamma(B^0 \to \ell^- X)}$$
$$= -\mathrm{Re}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{\rm SM} \frac{\sin 2\phi_{B_d}}{C_{B_d}} + \mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{\rm SM} \frac{\cos 2\phi_{B_d}}{C_{B_d}}$$

SM prediction $(-1.06\pm0.09)10^{-3}$

Direct measurement $(-0.3\pm5.0)10^{-3}$

Laplace, Ligeti, Nir and Perez Phys.Rev.D 65:094040,2002



Similar constraint available both Bs decays

$\Delta\Gamma$ for B_d and B_s

$$\frac{\Delta\Gamma_q}{\Delta m_q} = -2\frac{\kappa}{C_{B_q}}\left\{\cos\left(2\phi_{B_q}\right)\left(n_1 + \frac{n_6 B_2 + n_{11}}{B_1}\right) - \frac{\cos\left(\phi_q^{SM} + 2\phi_{B_q}\right)}{R_t^q}\left(n_2 + \frac{n_7 B_2 + n_{12}}{B_1}\right) + \frac{\cos\left(2(\phi_q^{SM} + \phi_{B_q})\right)}{R_t^{q^2}}\right.$$

$$\left.\left(n_3 + \frac{n_8 B_2 + n_{13}}{B_1}\right) + \cos\left(\phi_q^{Pen} + 2\phi_{B_q}\right) C_q^{Pen}\left(n_4 + n_9\frac{B_2}{B_1}\right) - \cos\left(\phi_q^{SM} + \phi_q^{Pen} + 2\phi_{B_q}\right)\frac{C_q^{Pen}}{R_t^q}\left(n_5 + n_{10}\frac{B_2}{B_1}\right)\right\}$$

- The constraint on B_d is not effective (experimental error~ 10 times the precision from the rest of the fit)

	SM	SM+NP	exp
$10^3\,\Delta\Gamma_d/\Gamma_d$	2.8 ± 2.7	2.0 ± 1.8	9 ± 37
$\Delta\Gamma_s/\Gamma_s$	0.10 ± 0.06	0.00 ± 0.08	0.25 ± 0.09

- The experimental measurement of $\Delta\Gamma_s$ actually measures $\Delta\Gamma_s\cos(\beta_s+\phi_{Bs})$ (Dunietz et al., hep-ph/0012219)
- NP can only decrease the experimental result wrt the SM value
- Experimental WA > SM expectation (NP suppressed)

NLO calculation of the matrix element of B meson mixing

Ciuchini et al. JHEP 0308:031,2003.

Same Sign dilepton charge asymmetry

Ratio of B_d and B_s production at Tevatron

Semileptonic asymmetries of Bd and Bs mesons

$$A_{CH} = \frac{1}{4}\left(A_{\rm SL}^{d} + \frac{f_s \chi_{s0}}{f_d \chi_{d0}} A_{\rm SL}^{s}\right)$$

$$\overset{(-)}{\chi}_q = \frac{\frac{\Delta\Gamma_q}{\Gamma_q}^2 + 4\frac{\Delta m_q}{\Gamma_q}^2}{\frac{\Delta\Gamma_q}{\Gamma_q}^2(\overset{(-)}{z}_q - 1) + 4(2\overset{(-)}{z}_q + \frac{\Delta m_q}{\Gamma_q}^2(1 + \overset{(-)}{z}_q))}$$

With $z = |q/p|^2$ and $\bar{z} = |p/q|^2$

From NLO calculation of the B meson mixing

τ_{Bs} in Flavor Specific final states

- B_s and $\bar{B}_s$ lifetime difference induced by $\Delta\Gamma_s$
- Experimental fit done with a single exponential rather than two exponentials
- The “average” lifetime is a function of the width and width difference

τ_{Bs} in Flavor Specific final states

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

Time-dependent angular analysis

TAGGED	UNTAGGED
2-fold ambiguity	*4-fold ambiguity*
$(\pi-\phi_s, -\Delta\Gamma_s, \pi-\delta_{1,2})$	$(\pi+\phi_s, -\Delta\Gamma_s, \pm\delta_{1,2})$
	$(-\phi_s, \Delta\Gamma_s, \pm(\pi-\delta_{1,2}))$
	$(\pi-\phi_s, -\Delta\Gamma_s, \pm(\pi-\delta_{1,2}))$

$$\frac{d^4\Gamma}{dt\, d\cos\theta\, d\varphi\, d\cos\psi} \propto$$

Dunietz, Fleischer, Nierste
hep-ph/0012219

$$\begin{aligned}
&2\cos^2\psi(1-\sin^2\theta\cos^2\varphi)|A_0(t)|^2 \\
&+\sin^2\psi(1-\sin^2\theta\sin^2\varphi)|A_{\|}(t)|^2 \\
&+\sin^2\psi\sin^2\theta|A_\perp(t)|^2 \\
&+(1/\sqrt{2})\sin 2\psi\sin^2\theta\sin 2\varphi \mathrm{Re}(A_0^*(t)A_{\|}(t)) \\
&+\ (1/\sqrt{2})\sin 2\psi\sin 2\theta\cos\varphi \mathrm{Im}(A_0^*(t)A_\perp(t)) \\
&-\ \sin^2\psi\sin 2\theta\sin\varphi \mathrm{Im}(A_{\|}^*(t)A_\perp(t)).
\end{aligned}$$

$$|A_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma t}\left[\cosh\frac{\Delta\Gamma\, t}{2} - |\cos\phi|\sinh\frac{|\Delta\Gamma|\, t}{2} + \sin\phi\,\sin(\Delta m\, t)\right]$$

$$|\overline{A}_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma t}\left[\cosh\frac{\Delta\Gamma\, t}{2} - |\cos\phi|\sinh\frac{|\Delta\Gamma|\, t}{2} - \sin\phi\,\sin(\Delta m\, t)\right]$$

$$\mathrm{Im}\{A_0^*(t)A_\perp(t)\} = |A_0(0)|\,|A_\perp(0)|\,e^{-\Gamma t}$$

$$\times\left[\sin\delta_2\,\cos(\Delta m\, t) - \cos\delta_2\,\cos\phi\,\sin(\Delta m\, t) - \cos\delta_2\,\sin\phi\,\sinh\frac{\Delta\Gamma\, t}{2}\right]$$

$$\mathrm{Im}\{\overline{A}_0^*(t)\overline{A}_\perp(t)\} = |A_0(0)|\,|A_\perp(0)|\,e^{-\Gamma t}$$

$$\times\left[-\sin\delta_2\,\cos(\Delta m\, t) + \cos\delta_2\,\cos\phi\,\sin(\Delta m\, t) - \cos\delta_2\,\sin\phi\,\sinh\frac{\Delta\Gamma\, t}{2}\right]$$

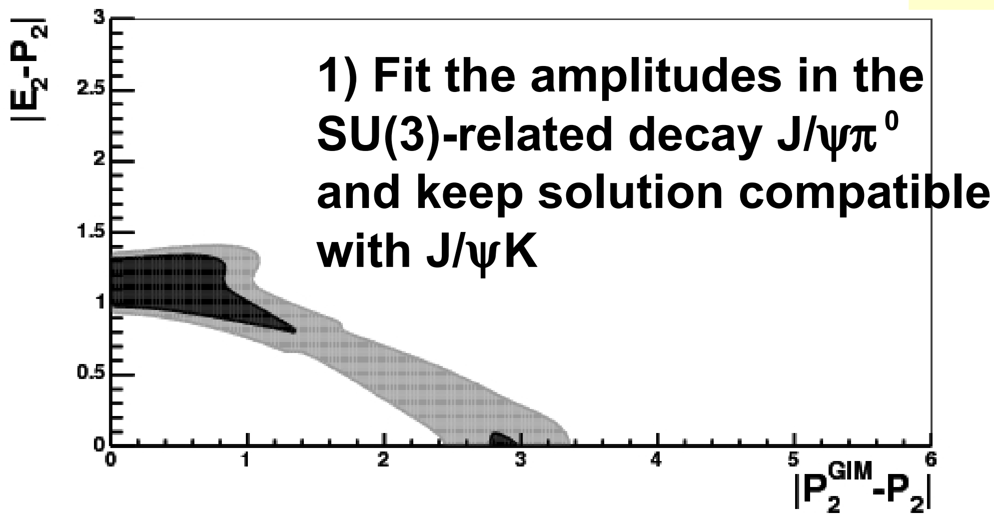
Theory error on sin2β

A.Buras, L.Silvestrini
Nucl.Phys.B569:3-52(2000)

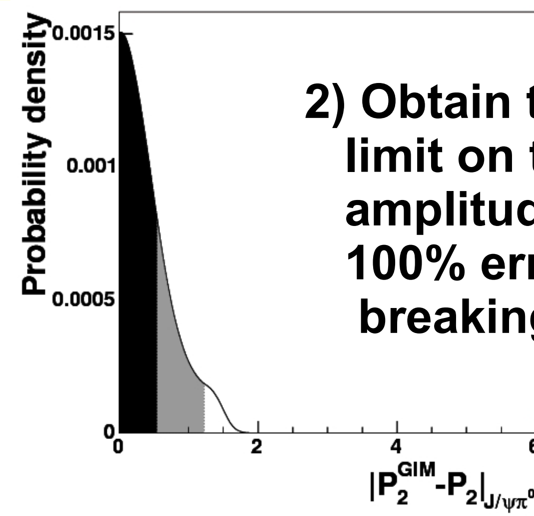
Channel	Cl.	E_1 1	E_2 $\frac{1}{N}$	EA_2 $\frac{1}{N^2}$	A_2 $\frac{1}{N}$	P_1 $\frac{1}{N}$	P_2 $\frac{1}{N^2}$	P_3 1	P_1^{GIM} 1	P_2^{GIM} $\frac{1}{N^2}$	P_3^{GIM} 1	P_4 1	P_4^{GIM} $\frac{1}{N^3}$
$B_d \to J/\psi K^0$			λ^2	–	–	–	λ^2			λ^4			–
$B_d \to \pi^0 J/\psi$	D	–	λ^3	λ^3	–	–	λ^3	–	–	λ^3	–	$[\lambda^3]$	$[\lambda^3]$

$V^*_{cb}V_{cs}$ $V^*_{tb}V_{ts}$ $V^*_{ub}V_{us}$

$V^*_{cb}V_{cd}$ $V^*_{tb}V_{td}$ $V^*_{ub}V_{ud}$

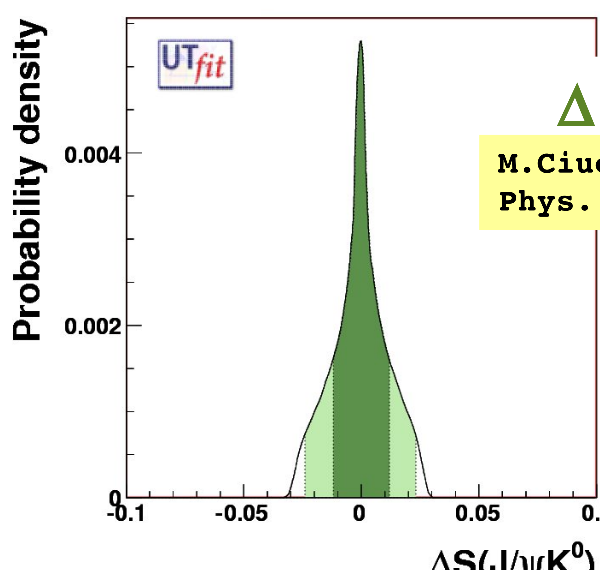


1) Fit the amplitudes in the SU(3)-related decay J/ψπ⁰ and keep solution compatible with J/ψK



2) Obtain the upper limit on the penguin amplitude and add 100% error for SU(3) breaking

3) Fit the amplitudes in J/ψK⁰ imposing the upper bound on the CKM suppressed amplitude and extract the error on sin2β



$\Delta S = 0.000 \pm 0.012$

M.Ciuchini, M.Pierini, L.Silvestrini
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