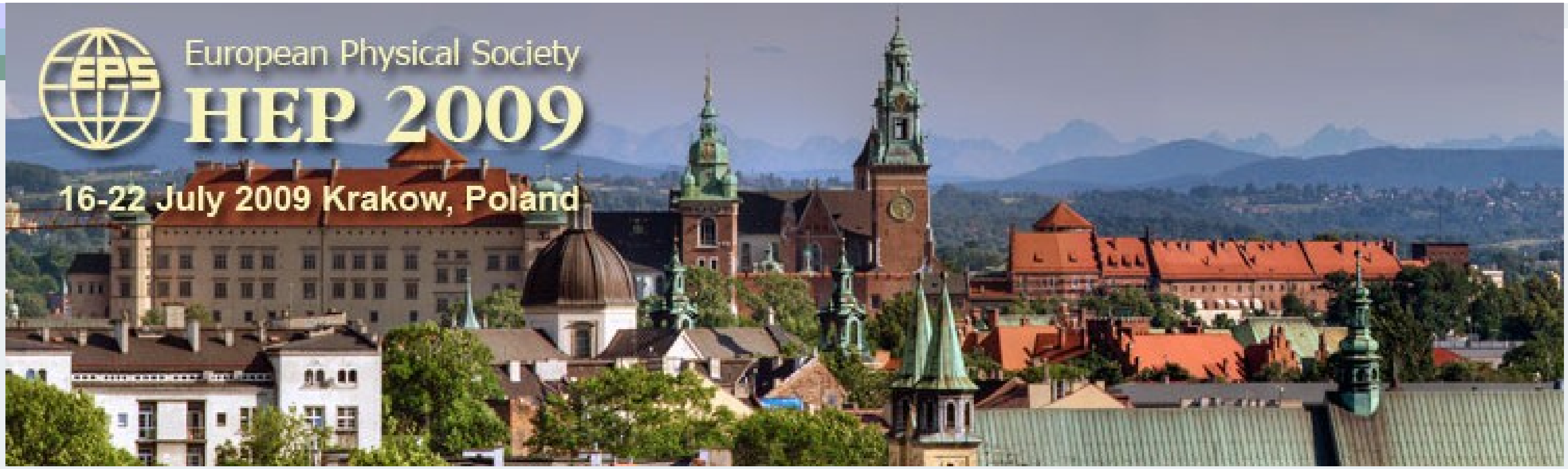


Update on the Unitarity Triangle Analysis (UTA):

(on behalf of the UTfit Collaboration)

www.utfit.org

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

Status of the UTA within the Standard Model (SM)

→ high precision and global success

Status of the UTA beyond the SM

→ evidence of New Physics (NP) at ~2.9 σ in the B_s system
→ bounds on the NP scale from the effective field theory analysis

Cecilia Tarantino
Università Roma Tre and INFN

The UTA within the Standard Model

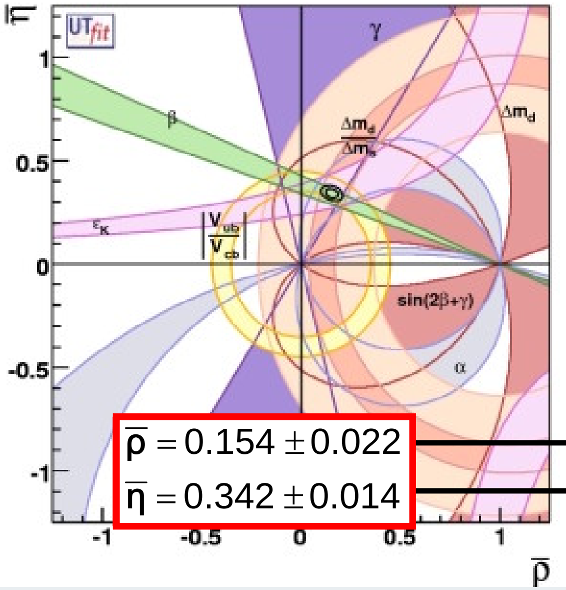
The experimental constraints:

$$\varepsilon_K, \Delta m_d, \left|\frac{\Delta m_s}{\Delta m_d}\right|, \left|\frac{V_{ub}}{V_{cb}}\right|$$ ⇨ relying on theoretical calculations of hadronic matrix elements

$$\sin 2\beta, \cos 2\beta, \alpha, \gamma(2\beta+\gamma)$$ ⇨ independent from theoretical calculations of hadronic parameters

overconstrain the CKM parameters consistently

SM analysis



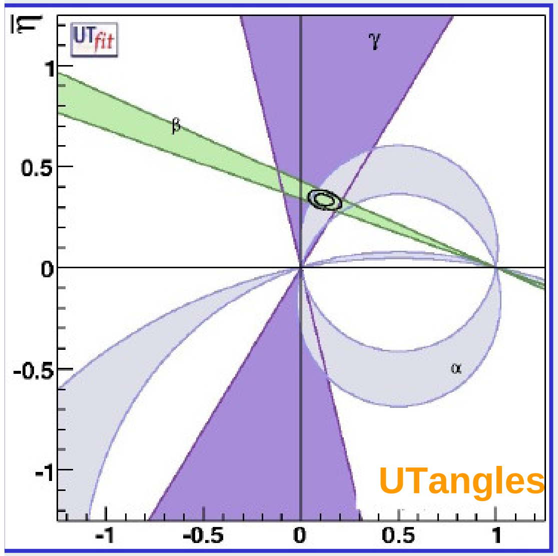
$\bar\rho = 0.154 \pm 0.022$ → ~14%

$\bar\eta = 0.342 \pm 0.014$ → ~ 4%

The UTA has established that the CKM matrix is the dominant source of flavour mixing and CP violation

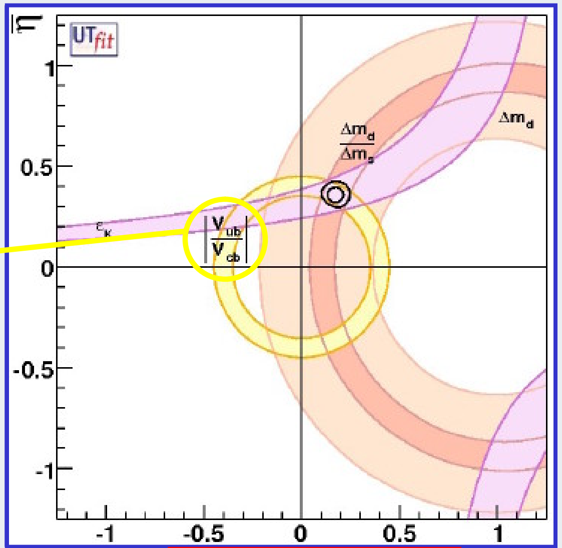
Due to many experimental constraints various UT analyses can be compared

Angles only (free from th. hadr. par.)



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

Without angles constraints



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

Good agreement

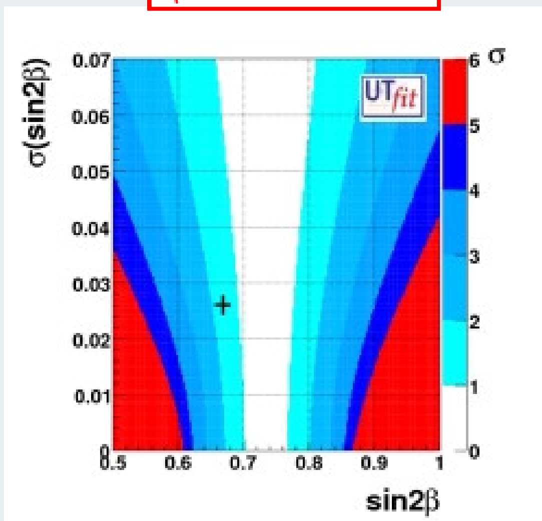
Small difference due to V_{ub}: average incl.-excl.

•V_{ub} from UTangles is in good agreement with $V_{ub}^{excl.}$

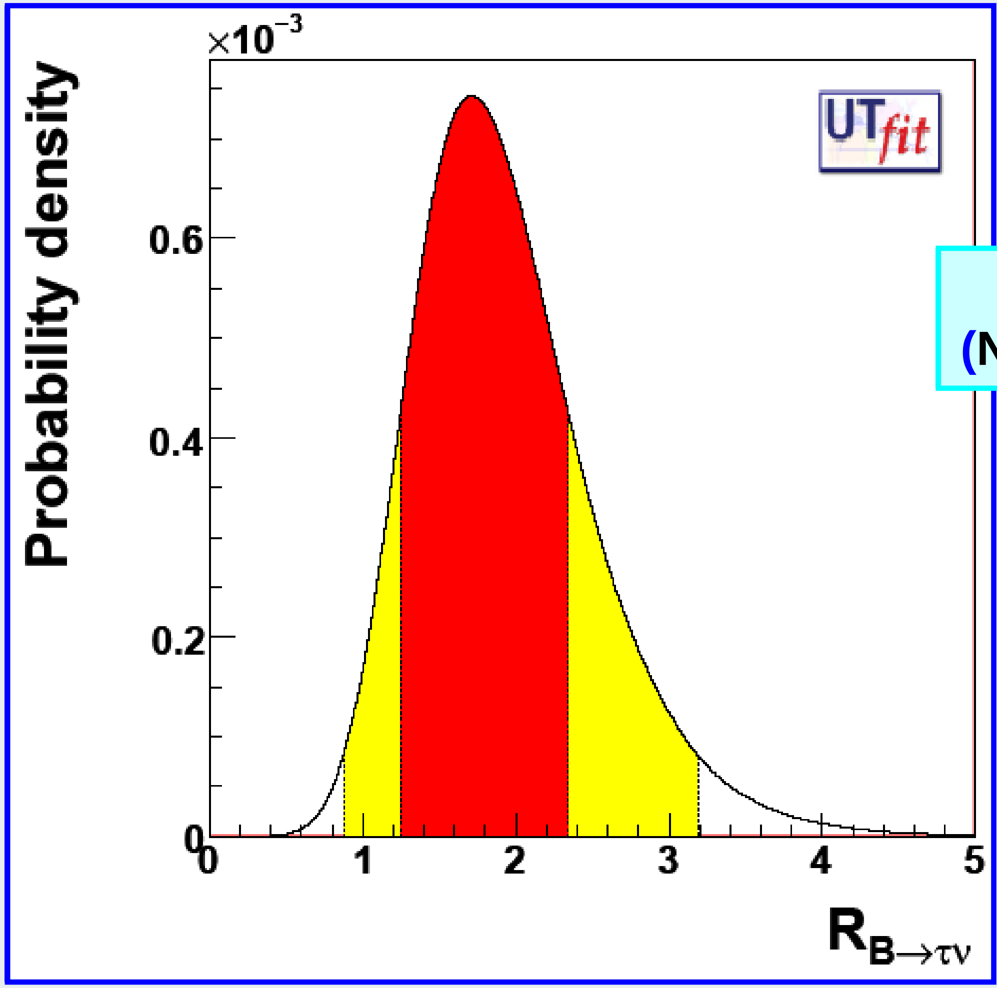
$$\left|V_{ub}^{incl.}\right| = (40 \pm 4)10^{-4} > \left|V_{ub}^{excl.}\right| = (35 \pm 4)10^{-4}$$

Their difference has decreased: 0.9 σ, because of recent inclusive analyses
(P.Gambino et al., 0707.2493; U.Aglietti at al. 0711.0860)
and BaBar data (B.Aubert et al., 0708.3702)

This (small) difference reflects into Sin2β: the measured value of sin2β from B ->Jψ K_S is ~1.5 σ smaller than the fitted value



$B \to \tau\nu$



$$R_{B\to\tau\nu} \equiv \frac{Br(B \to \tau\nu)_{exp}}{Br(B \to \tau\nu)_{SM(UTfit)}}$$

$R_{B\to\tau\nu}$ = 1.79±0.55 is larger than 1
(N.B. a charged Higgs cannot explain it)

The experimental measurement has a 26% uncertainty (HFAG 2009)

Some hadronic quantities can be extracted from the (overcostraint) UTA and compared to Lattice calculations *

*** assuming the SM validity!!!**

Extracting them as free parameters from the UTA:
(UTfit, update of hep-ph/0606167)

$\hat{B}_K^{UT}=0.75\pm0.07$

$f_{Bs}\sqrt{\hat{B}_{Bs}}^{UT}=265\pm4$ MeV

$\xi^{UT}=1.25\pm0.06$

Averaging recent accurate Lattice results:
(V.Lubicz, C.T., 0807.4605)

$\hat{B}_K^{LAT}=0.75\pm0.07$

$f_{Bs}\sqrt{\hat{B}_{Bs}}^{LAT}=270\pm30$ MeV

$\xi^{LAT}=1.21\pm0.04$

- **Recent unquenched Lattice calculations point towards (~4%) smaller values**
(RBC, hep-ph/0702042;
C.Aubin et al., 0905.3947)

- **Several calculations with continuum extrapolation are planned and looked forward**
→ Lattice09@Beijing in 10 days!

Remarkable agreement:
- **Additional evidence of the SM success in describing flavour physics**
- **Reliability of Lattice QCD**

Further improvements in Lattice calculations of B_K and ξ will increase the UTA accuracy

Model-independent UTA: bounds on deviations from the SM (+CKM)

- Parametrize generic NP in $\Delta F=2$ processes, in all sectors
- Use all available experimental info
- Fit simultaneously the CKM and NP parameters

NP contributions in the mixing amplitudes:

$$H^{\Delta F=2} = m + \frac{i}{2}\Gamma \qquad A = m_{12} = \langle M|m|\bar{M}\rangle \qquad \Gamma_{12} = \langle M|\Gamma|\bar{M}\rangle$$

K mixing amplitude (2 real parameters):

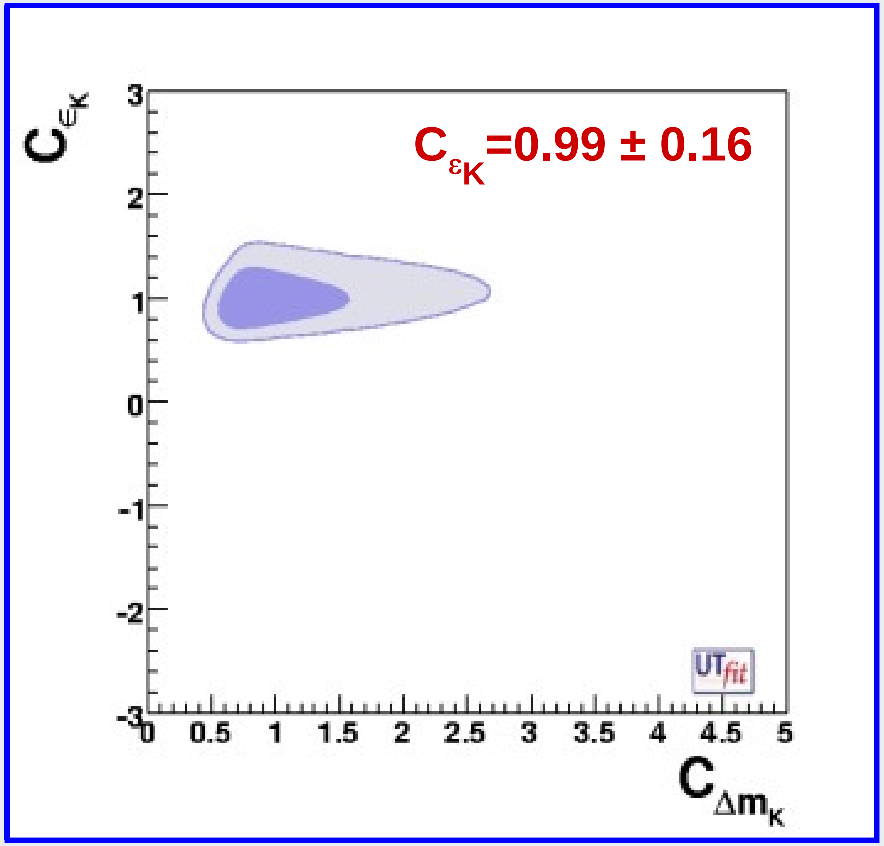
$$\mathrm{Re}\,A^K = C_{\Delta m_K}\,\mathrm{Re}\,A_K^{SM} \qquad \mathrm{Im}\,A_K = C_{\varepsilon_K}\,\mathrm{Im}\,A_K^{SM}$$

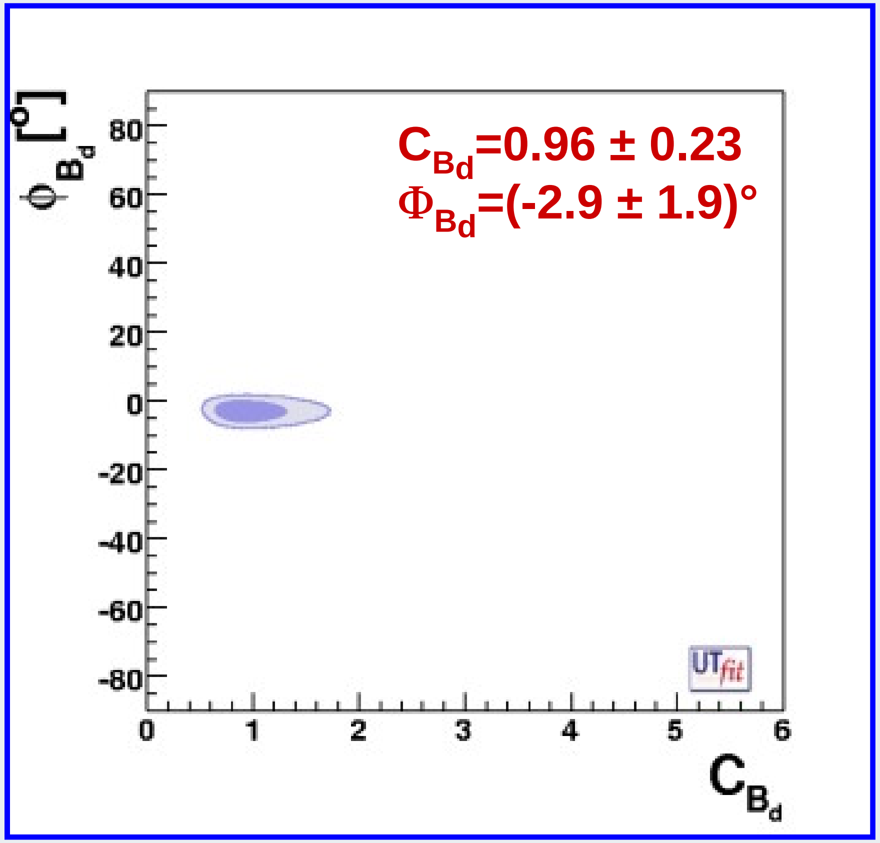
B_d and B_s mixing amplitudes (2+2 real parameters):

$$A_q e^{2i\phi_q} = C_{B_q} e^{2i\phi_{B_q}} A_q^{SM} e^{2i\phi_q^{SM}} = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_q^{NP}-\phi_q^{SM})}\right) A_q^{SM} e^{2i\phi_q^{SM}}$$

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

Results for the K and B_d mixing amplitudes





Contributions to ε_K not included yet
(pointed out by A.J.Buras and D.Guadagnoli 0805.3887)

They would decrease ε_K by **~8%**, thus conspiring with a small **B_K** for an ε_K smaller than the exper. measurement

The **sin2β** tension produces nowadays a **~1.5 σ** effect in ϕ_{Bd}

NP?

Importance of reducing theoretical uncertainties!

In 2008 both CDF and DØ published the tagged time-dependent angular analysis of $B_s \to J/\psi\ \phi$

2D likelihood ratio for $\Delta\Gamma$ and ϕ_s

2-fold ambiguity present, no assumption on the strong phases

arXiv:0712.2397

7-parameter fit + correlation matrix or 1D likelihood profiles of $\Delta\Gamma$ and ϕ_s

2-fold ambiguity removed using strong phases from B -> J/Ψ K* + SU(3) + ?

arXiv:0802.2255

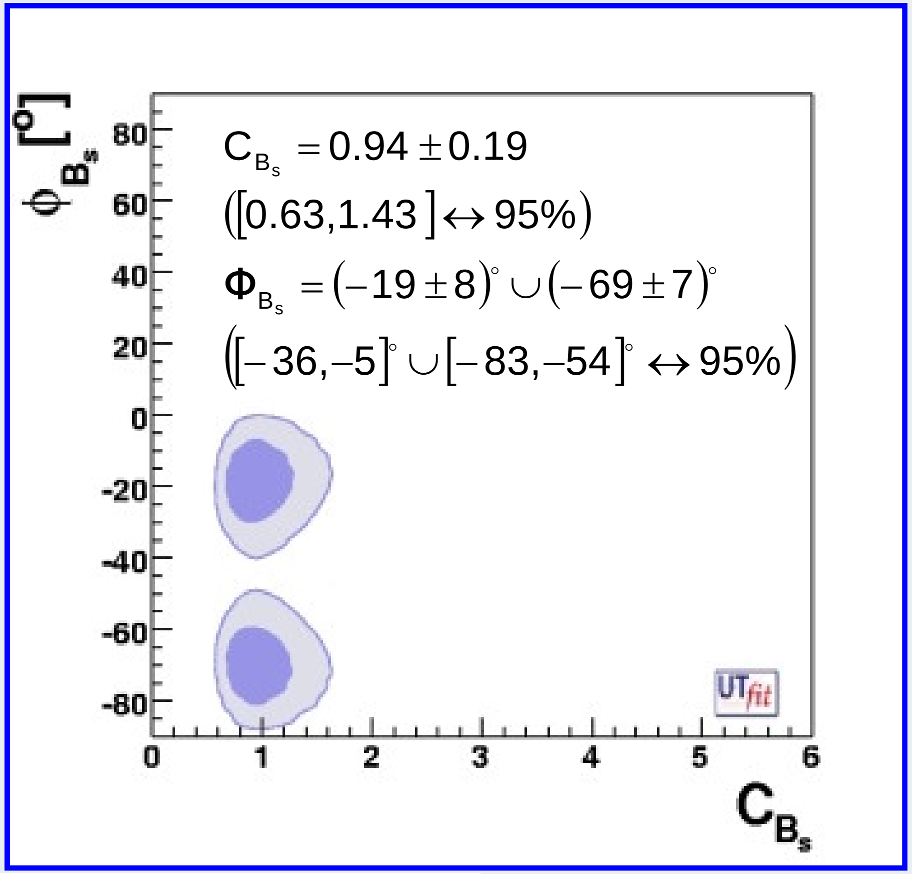
At ICHEP '08:

1. DØ released the 2D likelihood scan w/o assumptions on the strong phases
2. New measurement of A_{SL}^s, now $A_{SL}^s = (-0.20 \pm 1.19)\ \%$

All the exp. info have been combined

(UPDATE OF UTfit Coll. 0803.0659)

UPDATED UTfit analysis:
SM @ 2.9 σ



HFAG: 2.2σ (0808.1297)
CKMfitter: 2.7σ (see talk by Jose Ocariz)

More than 2σ deviation for every statistical approach!

Enlarged data sample: 1.35 fb^{-1} -> 2.8 fb^{-1}
opposite-side tagging only (equivalent to ~2 fb^{-1})

CDF analysis: SM compatibility 15%(1.5σ)->7%(1.8σ)

(New CDF likelihood not available yet)

If this evidence is confirmed ⇨
NP with new sources of flavour violation is required

•Minimal Flavour Violation (MFV) models are ruled out (including the simplest MSSM)

•A clear pattern of flavour violation in NP emerges:
1↔ 2: strongly suppressed
1↔ 3: ≤O(10%)
2↔ 3: O(1)

•This pattern can be explained by nonabelian flavour symmetries and in some SUSY-GUTs

Flavour Physics is highly sensitive to NP: The Effective Field Theory (EFT) analysis

UTfit

The mixing amplitudes $A_q e^{2i\phi_q} = \langle \bar{M}_q | H_{eff}^{\Delta F=2} | M_q \rangle$

$$H_{eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i(\mu) Q_i(\mu) + \sum_{i=1}^{3} \tilde{C}_i(\mu) \tilde{Q}_i(\mu)$$

$$Q_1 = \bar{q}_L^\alpha \gamma_\mu b_L^\alpha \, \bar{q}_L^\beta \gamma^\mu b_L^\beta \qquad \text{(SM/MFV)}$$

$$Q_2 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_R^\beta b_L^\beta \qquad Q_3 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_R^\beta b_L^\alpha$$

$$Q_4 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad Q_5 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_L^\beta b_R^\alpha$$

$$\tilde{Q}_1 = \bar{q}_R^\alpha \gamma_\mu b_R^\alpha \, \bar{q}_R^\beta \gamma^\mu b_R^\beta$$

$$\tilde{Q}_2 = \bar{q}_L^\alpha b_R^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad \tilde{Q}_3 = \bar{q}_L^\alpha b_R^\beta \, \bar{q}_L^\beta b_R^\alpha$$

The high scale coefficients $C_i(\Lambda)$ can be extracted from the data (switching on one operator per time)

$$C_i(\Lambda) = \frac{L F_i}{\Lambda^2} \Rightarrow \Lambda = \sqrt{\frac{L F_i}{C_i(\Lambda)}}$$

Tree/strong inter. NP: $L \sim 1$

Perturbative NP: $L \sim \alpha_s^2, \alpha_W^2$

MFV	next-to-MFV	generic
- $F_1 = F_{SM} \sim (V_{tq} V_{tb}^*)^2$ - $F_{i\neq1} = 0$	- $\lvert F_i \rvert \sim F_{SM}$ - arbitrary phases	- $\lvert F_i \rvert \sim 1$ - arbitrary phases

Present lower bound on the NP scale

From B and K data (TeV@95%)

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

* $\Delta F=2$ chirality-flipping operators are RG enhanced and thus probe larger NP scale (that can be pushed beyond the LHC reach)

* A suppression of the NP contribution in $1 \leftrightarrow 2$ transitions weakens the lower bound on the NP scale

In the presence of a NP evidence, also an upper bound is provided

From the B_s system (TeV@95%)

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

upper bound << lower bound!!

⇩

The pattern of NP flavour couplings cannot be SM-like nor general

Data suggest some hierarchy in NP, stronger than in the SM (e.g. some SUSY-GUTs)

Conclusions

The (overconstraint) UTA proves that the CKM matrix is the dominant source of flavour mixing and CP violation

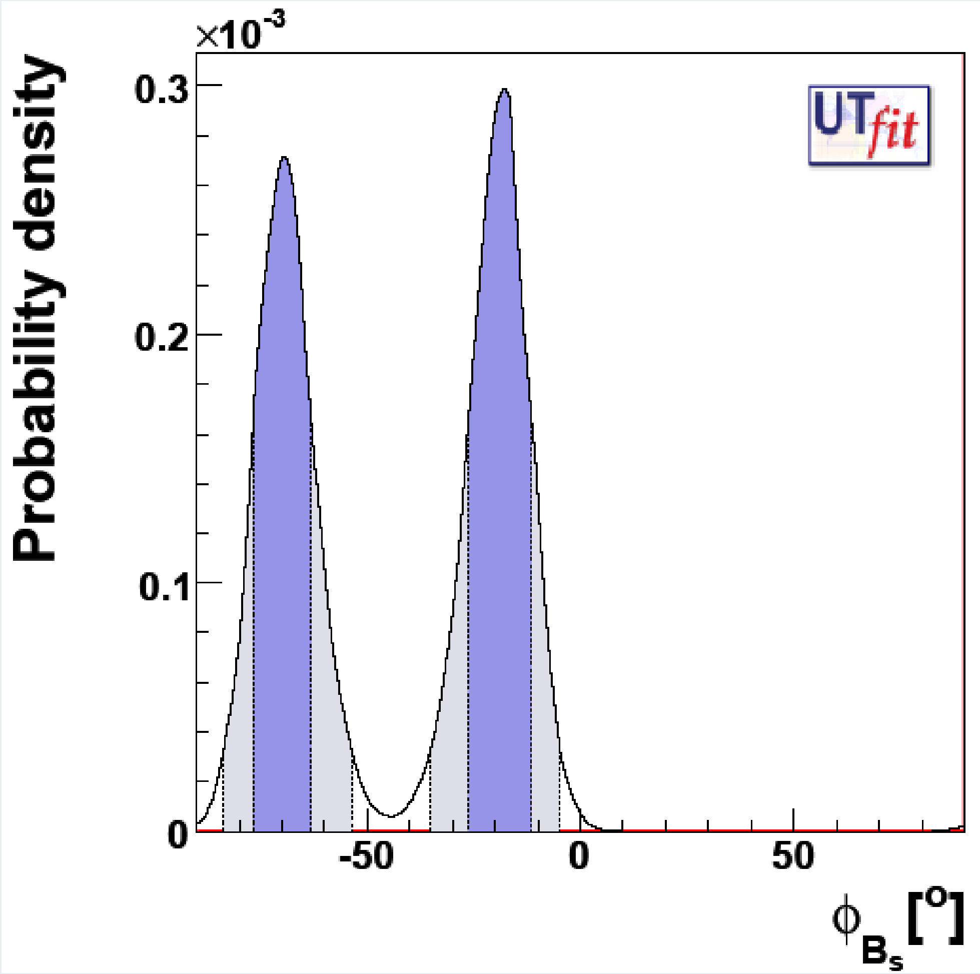
The updated UTfit combination of the Tevatron data gives a 2.9σ deviation of ϕ_{B_s} from the SM
(new CDF measurements still to be included)

The EFT analysis suggests that the pattern of NP flavour couplings is more hierarchical than in the SM

New data from the Tevatron and the LHC will be available soon!

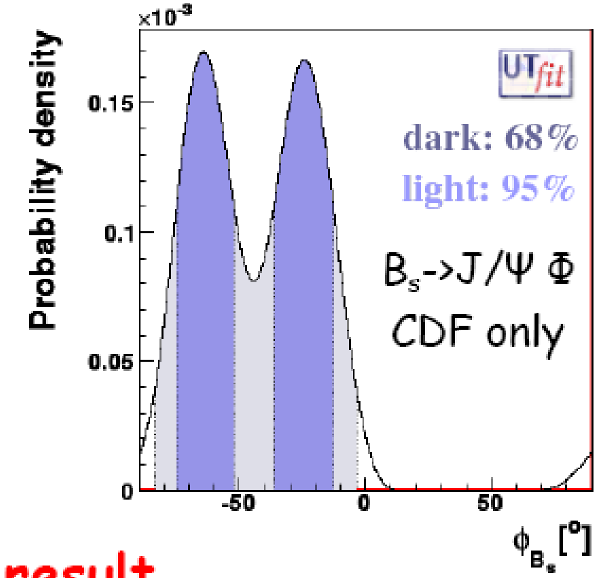

THANKS!

BACKUP

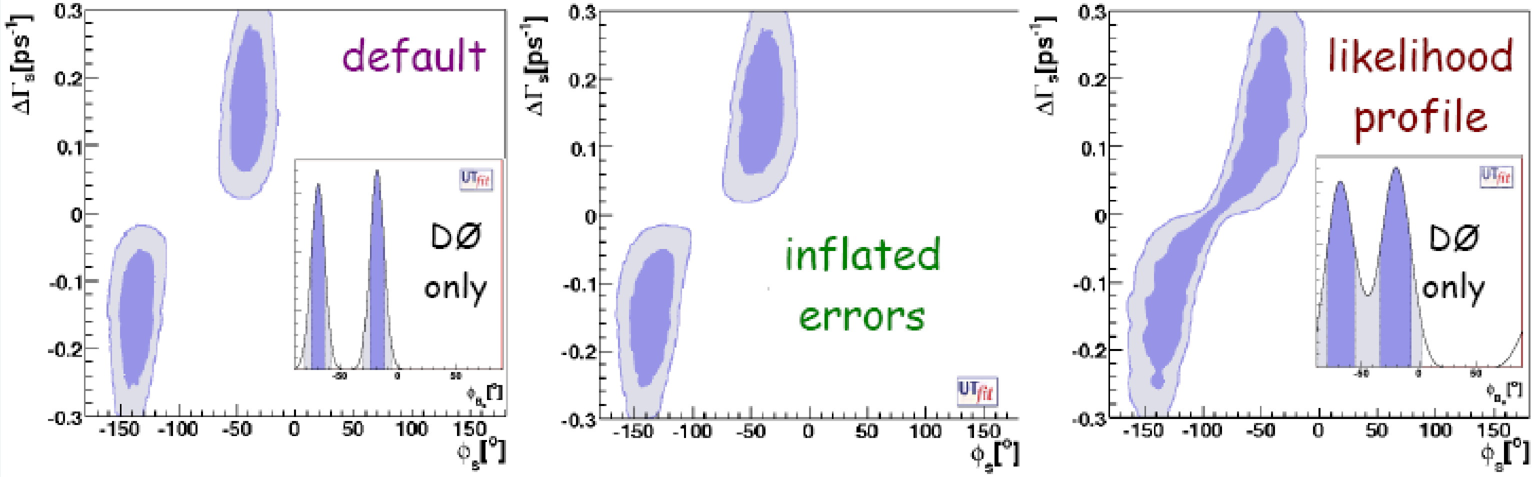


×10^-3
Probability density
0.3
0.2
0.1
0
-50
0
50
UTfit
ϕ_{B_s} [°]

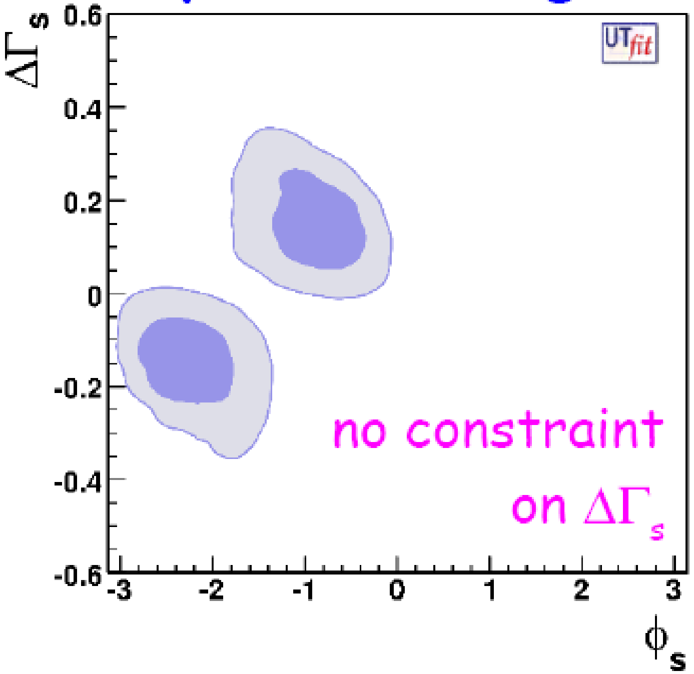
* gaussian: CDF likelihood+Gaussian DØ result with 2x2 corr. matrix
* inflated error: as above, but with error inflated to reproduce the 2σ range computed by DØ
* likelihood profile: using the 1D likelihood profiles for ϕ_s and $\Delta\Gamma_s$

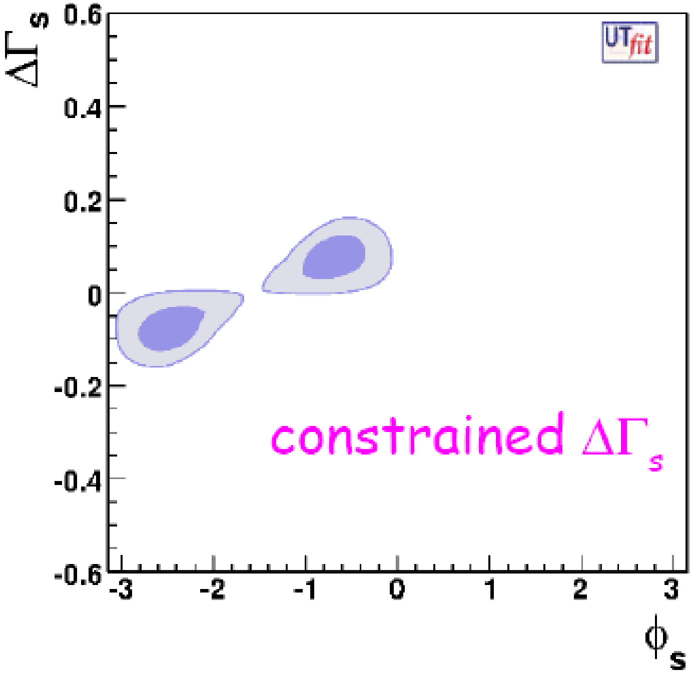


ambiguity reintroduced in the DØ result



The th input for $\Delta\Gamma_s$ is crucial: most of the exp allowed region has a too large $|\Delta\Gamma_s|$

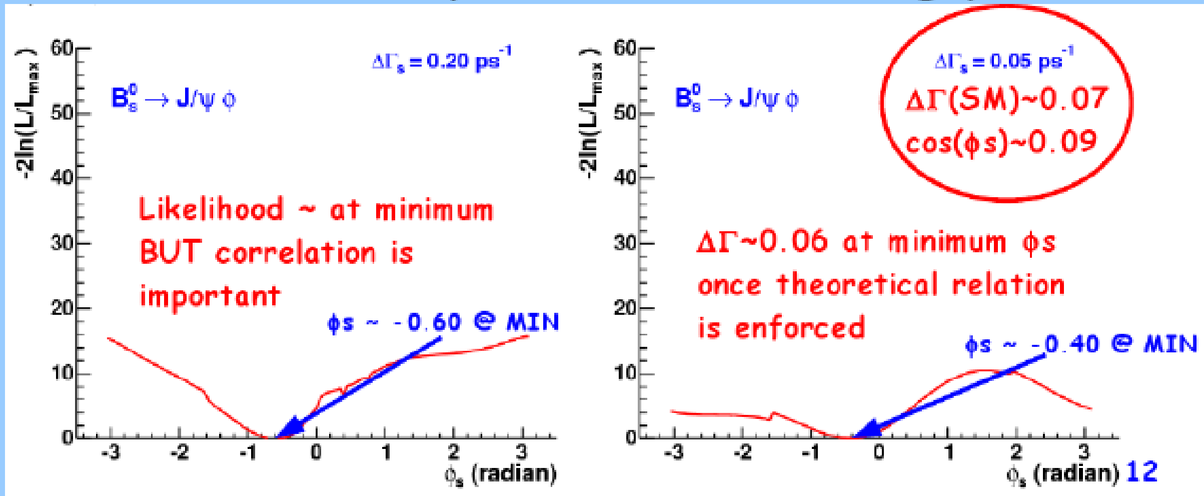




We use a conservative estimate of the SM error and allow NP to enter $\Delta\Gamma_s$ through NP penguins

ICHEP '08 update (i)

1. DØ released the 2D likelihood scan w/o assumptions on the strong phases

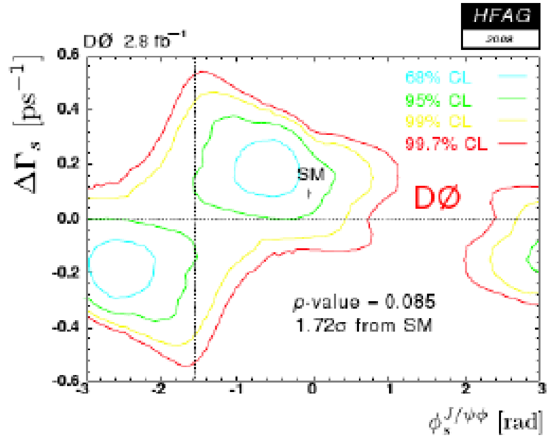


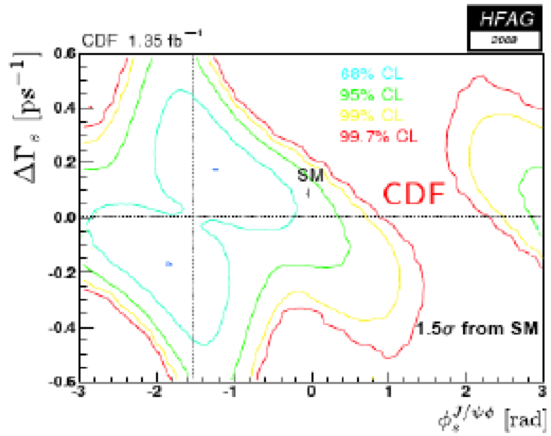
2. New measurement of A_{SL}^s, now $A_{SL}^s = (-0.20 \pm 1.19)\ \%$

Enlarged data sample: 1.35 fb^{-1} -> 2.8 fb^{-1}
opposite-side tagging only (equivalent to ~2 fb^{-1})

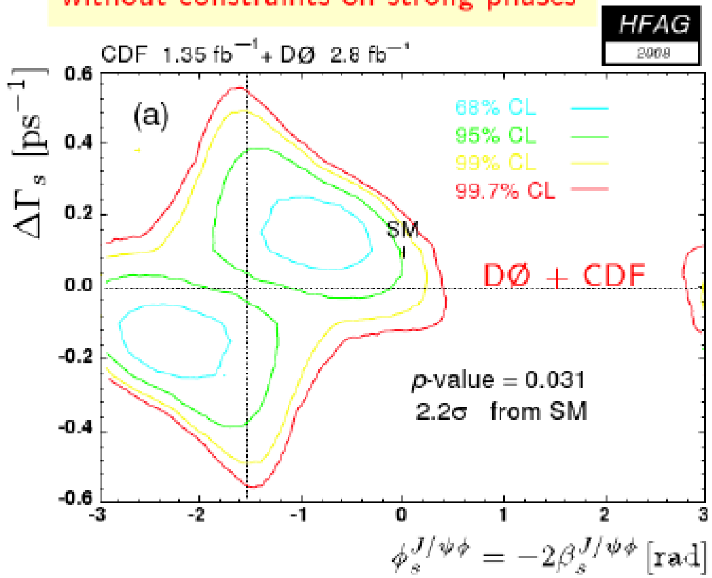
CDF analysis: SM compatibility 15%(1.5σ)->7%(1.8σ)

New HFAG combination





Combination of results
without constraints on strong phases



$\phi_s = -2.37^{+0.38}_{-0.27}$ rad, $-0.75^{+0.27}_{-0.38}$ rad

$\Delta\Gamma_s = -0.150^{+0.66}_{-0.59}$ ps^{-1}, $0.150^{+0.59}_{-0.66}$ ps^{-1}

90% C.L. intervals (1-d regions):

$\phi_s \in [-2.85, -1.65], [-1.47, -0.29]$

$\Delta\Gamma_s \in [-0.265, -0.036], [0.036, 0.265]$

New CDF results not included yet