V_{xb} 2009
SLAC
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Update of the Unitarity Triangle Analysis (UTA):

(on behalf of the UTfit Collaboration)

www.utfit.org

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Status of the UTA within the Standard Model (SM)

→ high precision and global success (but few tensions: $\varepsilon_K \leftrightarrow \sin(2\beta)$, $Br(B \rightarrow \tau\, \nu)$)

Status of the UTA beyond the SM

→ hint of New Physics (NP) at ~2.9 σ in the B_s system

→ bounds on the NP scale from the effective field theory analysis

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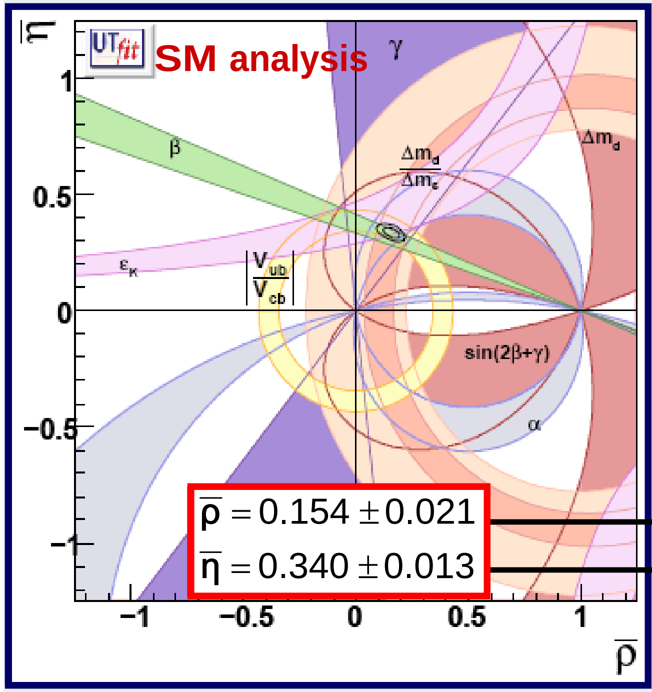
The UTA within the Standard Model

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

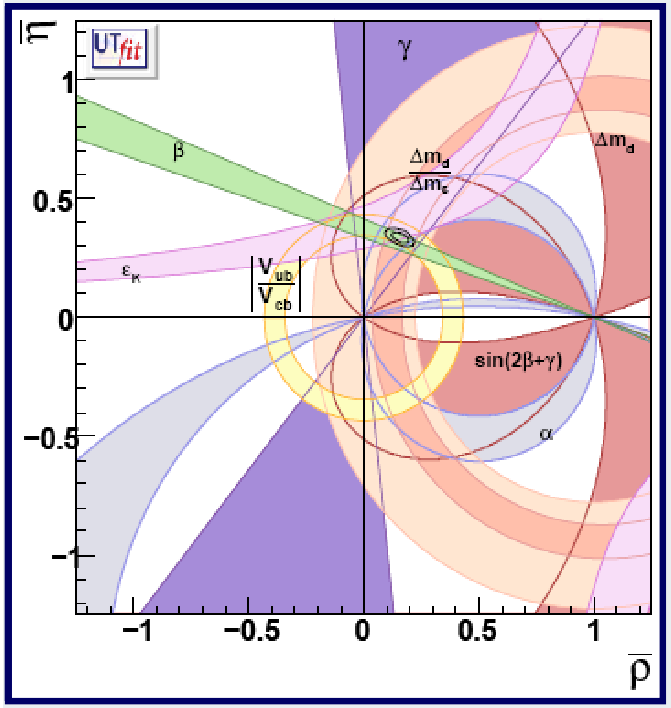
$\bar{\rho}$: ~14%

$\bar{\eta}$: ~ 4%

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

From a closer look

UTfit, 0909.5065



Update of the UTA after summer (after the EPS):
Inclusion of the corrections to ε_K pointed out by A.J.Buras and D.Guadagnoli (0805.3887)
⇒ decrease of the SM prediction of ε_K by ~8%

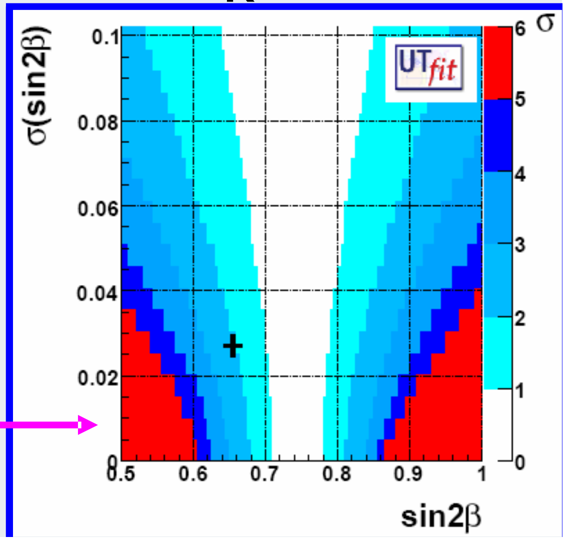
$$\epsilon_K = e^{i\phi_\epsilon} \sin\phi_\epsilon \left(\frac{\mathrm{Im}(M_{12}^K)}{\Delta M_K} + \xi \right)$$

$$\xi = \frac{\mathrm{Im}A_0}{\mathrm{Re}A_0}$$ → decreases ε_K by ~5%

$$\phi_\epsilon = (43.51 \pm 0.05)^\circ$$ → decreases ε_K by ~3%

The inclusion of the corrections to ε_K generates some tension between the experimental constraints: ε_K and sin(2β)

The indirect determination of sin(2β) turns out to be at ~2.0 σ from the experimental measurement



Due to many experimental constraints the UT turns out to be overcostraint

The UTA can be used to improve the knowledge of some inputs: e.g. $|V_{ub}|$

Input value in the UTA: $(36.7 \pm 2.1) \cdot 10^{-4}$
Output value from the UTA: $(35.2 \pm 1.1) \cdot 10^{-4}$

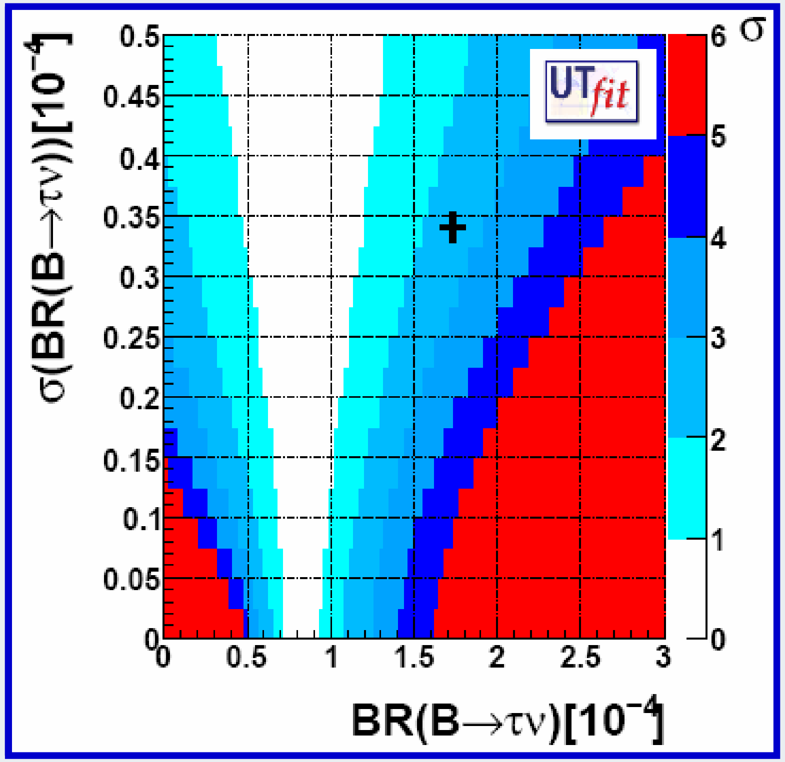
HFAG
Inclusive-exclusive average by V.Lubicz and C.T. (0807.4605)
[unquenched lattice results from FNAL/MILC 04 and HPQCD 06 + QCD sum rules (Duplancic et al. 08)]

The improved (by other constraints) determination of $|V_{ub}|$ (and f_B) reduces the uncertainty on the SM prediction of $Br(B \to \tau \nu)$ (from 24% to 13%) [UTfit, 0908.3470]

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

$B \to \tau\nu$

$BR(B\to\tau\nu)_{SM} = (0.84\pm0.11)\cdot10^{-4}$ turns out to be larger by ~2.5 σ than the experimental value (BaBar+Belle,2006-2008) $BR(B\to\tau\nu)_{exp} = (1.73\pm0.34)\cdot10^{-4}$



By generalizing the analysis, allowing for NP effects in $\Delta F=2$ processes, the deviation remains (~2.2 σ)

N.B. a charged Higgs could not easily explain the enhancement (due to other constraints, mainly $b\to s\gamma$)

$$\frac{BR(B\to\tau\nu)_{2HDM}}{BR(B\to\tau\nu)_{SM}} = \left(1-\tan^2\beta\,\frac{m_B^2}{m_{H^+}^2}\right)^2$$

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)

$\hat{B}_K^{UT} = 0.81 \pm 0.08$

$f_{Bs}\sqrt{\hat{B}_{Bs}}^{UT} = 265 \pm 4$ MeV

$\xi^{UT} = 1.25 \pm 0.06$

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

$\hat{B}_K^{LAT} = 0.75 \pm 0.07$

$f_{Bs}\sqrt{\hat{B}_{Bs}}^{LAT} = 270 \pm 30$ MeV

$\xi^{LAT} = 1.21 \pm 0.04$

•Recent unquenched Lattice calculations point towards (~3-4%) smaller values
(see new averages by J.Lahio, E.Lunghi, R.Van de Water, 0910.2928) $\hat{B}_K = 0.73 \pm 0.03$

N.B. a smaller value of B_K increases the tension ε_K – sin(2β)

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

An update of the Lattice averages is in program (~once per year)

The UTA beyond the Standard Model

Update after summer (after the EPS): decrease of the SM prediction of ε_K by ~3% [due to ϕ_ε=43.51°, while ξ=0 (difficult to estimate from ε'/ε beyond MFV)]

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

For $K-\bar{K}$ mixing, the NP parameters are found
in agreement with the SM expectations
(some effect can be seen once B_K is updated to a smaller value)

For $B_d-\bar{B}_d$ mixing, the mixing phase ϕ_{Bd} is found
1.5 σ away from the SM expectation
(reflecting a slight tension between $\sin(2\beta)$ and $|V_{ub}/V_{cb}|$)

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

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 -> $J/\Psi\ K^*$ + SU(3) + ?

arXiv:0802.2255

At ICHEP '08:

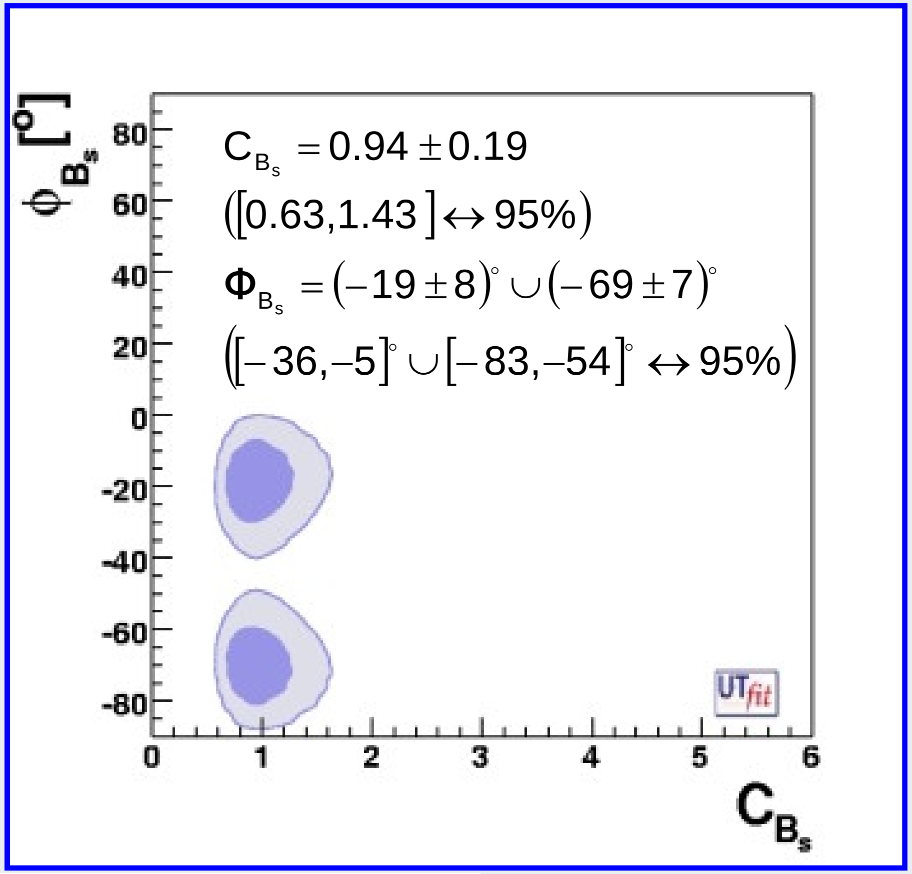
1. DØ released the 2D likelihood scan w/o assumptions on the strong phases
2. New measurement of A_{SL}^s, now $A_{SL}^s = (-0.20 \pm 1.19)\ \%$

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: 2.5σ (0810.3139)

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 deviation is confirmed ⇒ NP with new sources of flavour violation is required

UTfit

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

- A clear pattern of flavour violation in NP emerges:
  1↔ 2: 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~1

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

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

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

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)

We are looking for increased exp. accuracy in order to confirm or exclude a NP effect in the B_s system!


THANKS

BACKUP

The effect of quenching the strange quark has never been seen

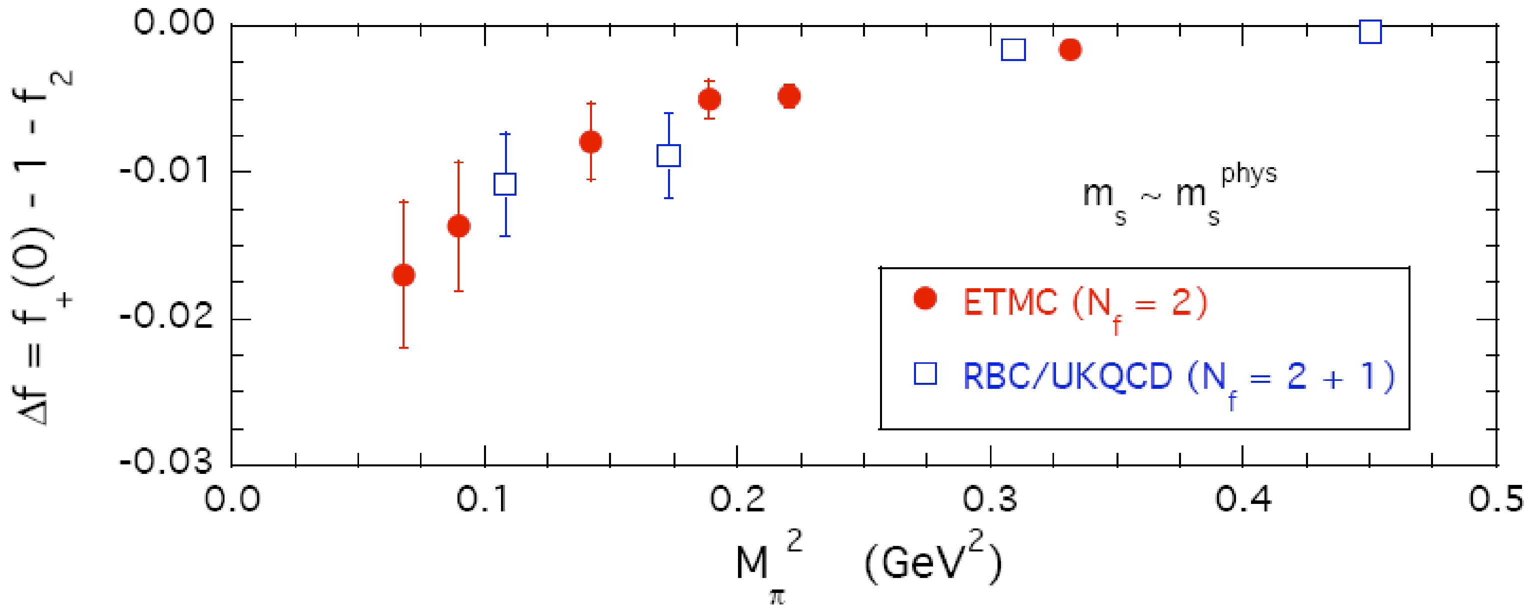
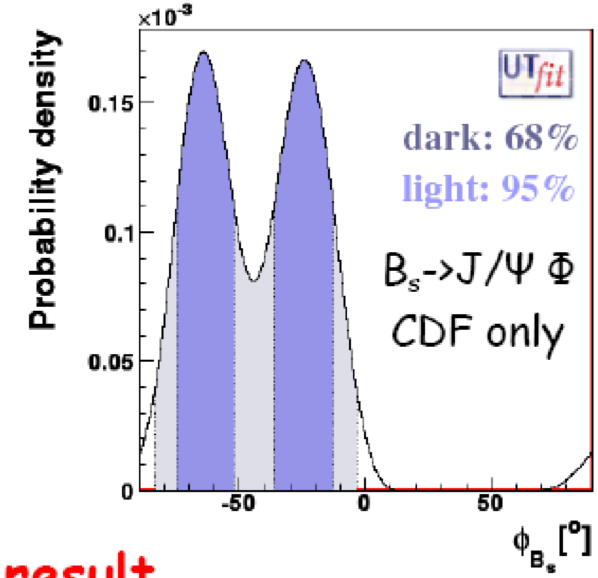
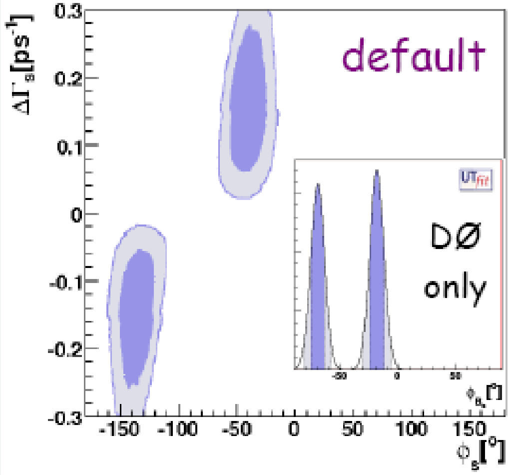


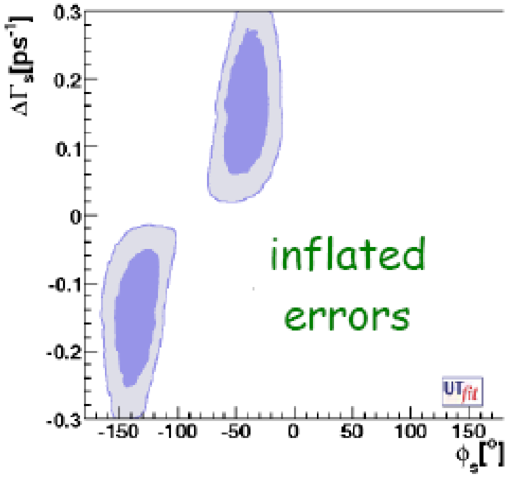
Figure 2: *Values of the $\mathcal{O}(p^6)$ term Δf [Eq. (2.6)] obtained by the ETM [8] and RBC/UKQCD [7] Collaborations taking into account the values of the NLO term f_2 appropriate for $N_f = 2$ and $N_f = 2+1$.*

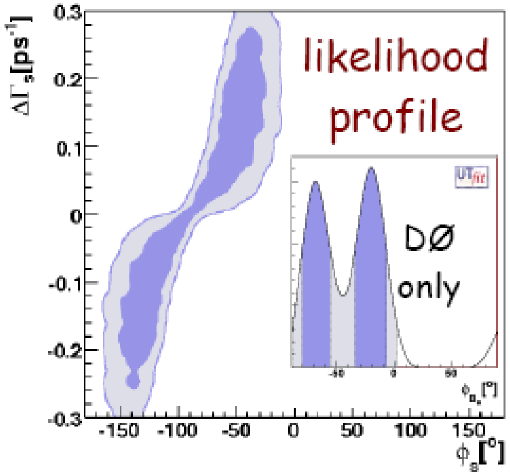
* gaussian: CDF likelihood+Gaussian DØ result with 2x2 corr. matrix
* inflated error: as above, but with error inflated to reproduce the 2σ range computed by DØ
* likelihood profile: using the 1D likelihood profiles for ϕ_s and $\Delta\Gamma_s$



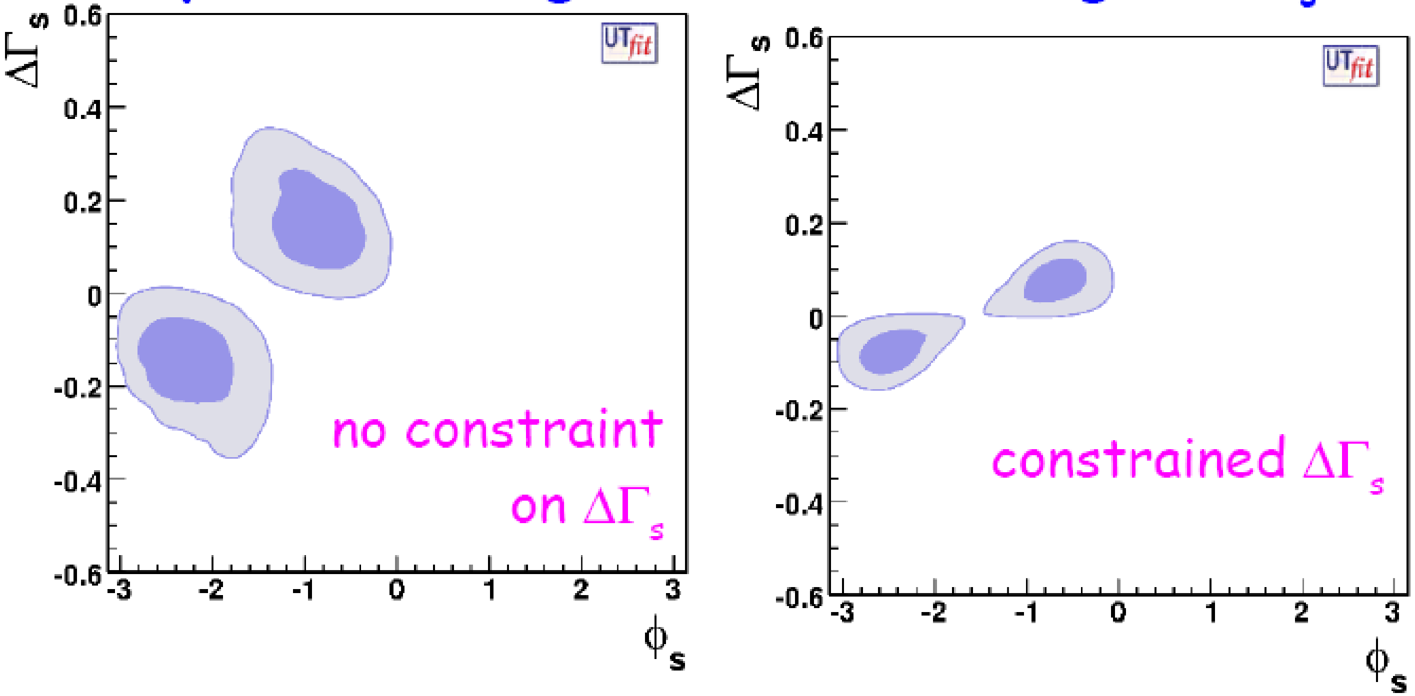
ambiguity reintroduced in the DØ result







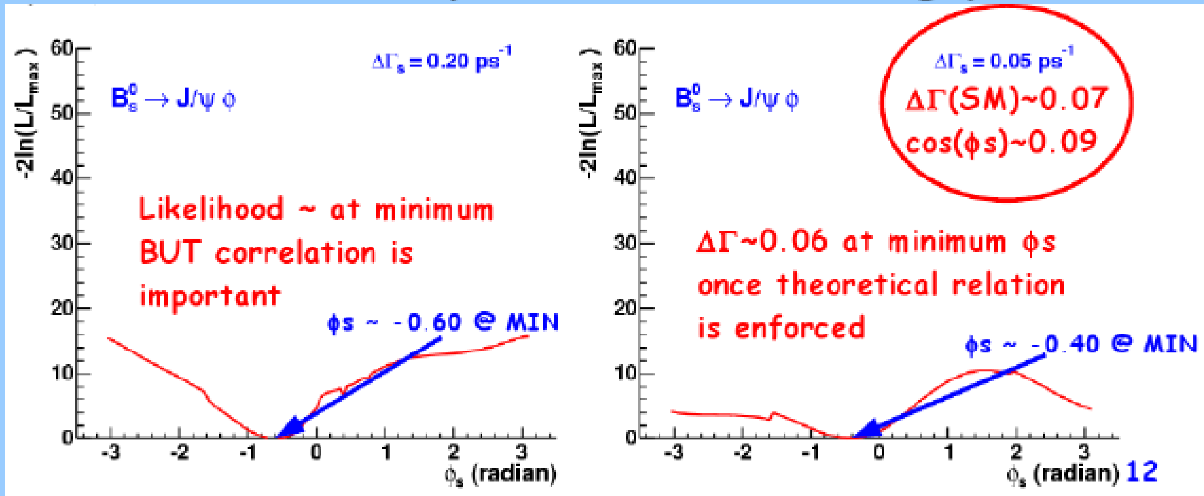
The th input for $\Delta\Gamma_s$ is crucial: most of the exp allowed region has a too large $|\Delta\Gamma_s|$



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

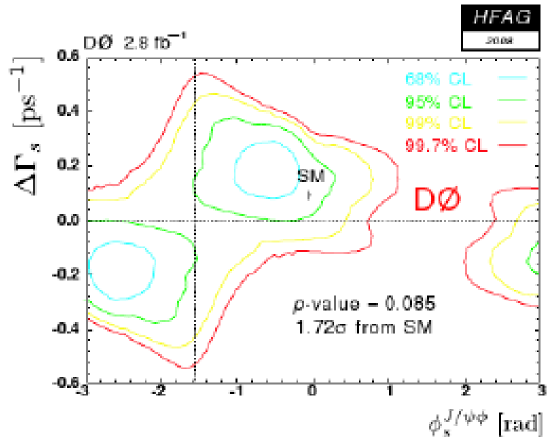


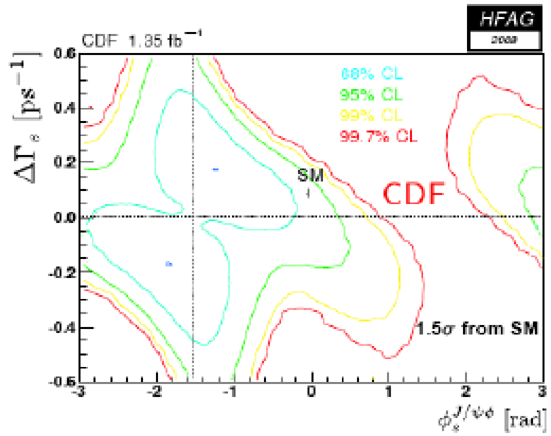
2. New measurement of A_{SL}^s, now $A_{SL}^s = (-0.20 \pm 1.19)\ \%$

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

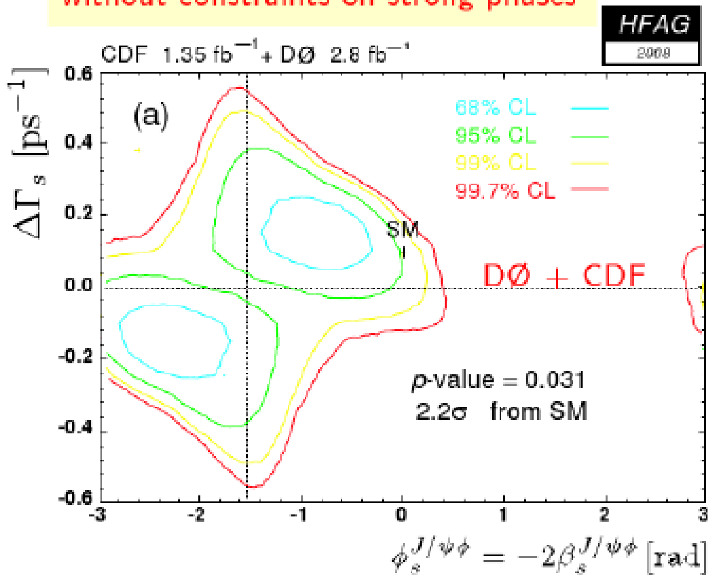
CDF analysis: SM compatibility 15%(1.5σ)->7%(1.8σ)

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