Some Implications of a Large Phase in B_s Mixing

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* **Quick summary of the ϕ_s determination**
  - the Tevatron measurements
  - the UTfit analysis

UTfit coll., arxiv:0803.0659 + updates

* **Implications of a large phase in B_s mixing**
  - model-independent & EFT analyses
  - MSSM with generic mass insertions
  - SUSY-GUTs

preliminary!!

UTfit coll. - MC, Silvestrini
MC, Masiero, Paradisi, Silvestrini

Phase of the SM B_s mixing amplitude

The SM contribution to CP violation in B_s mixing is small and rather well determined:

* $\sin 2\beta_s = 0.041 \pm 0.004$ (arbitrary NP)
  $= 0.037 \pm 0.002$ (SM or MFV)

The phase of the B_s mixing amplitude can be extracted from $B_s \to J/\psi\ \varphi$ with a small theoretical uncertainty

Hence observing a mixing phase significantly larger than 0.041 would be a <u>very clean signal</u> of NP in B_s mixing

New Physics in the mixing amplitudes

1. find out how much room is left for NP in $\Delta F=2$ transitions
   - add most general NP to all sectors
   - use all available experimental info
   - fit simultaneously for the CKM and the NP parameters (generalized UT fit)
2. perform an EFT analysis to put bounds on the NP scale
   - consider different choices of the FV and CPV couplings

UTfit collaboration
hep-ph/0509219, arXiv:0707.0636

1. parameterization of NP contributions to the mixing amplitudes

K mixing amplitude (2 real parameter):

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

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

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

Observables:

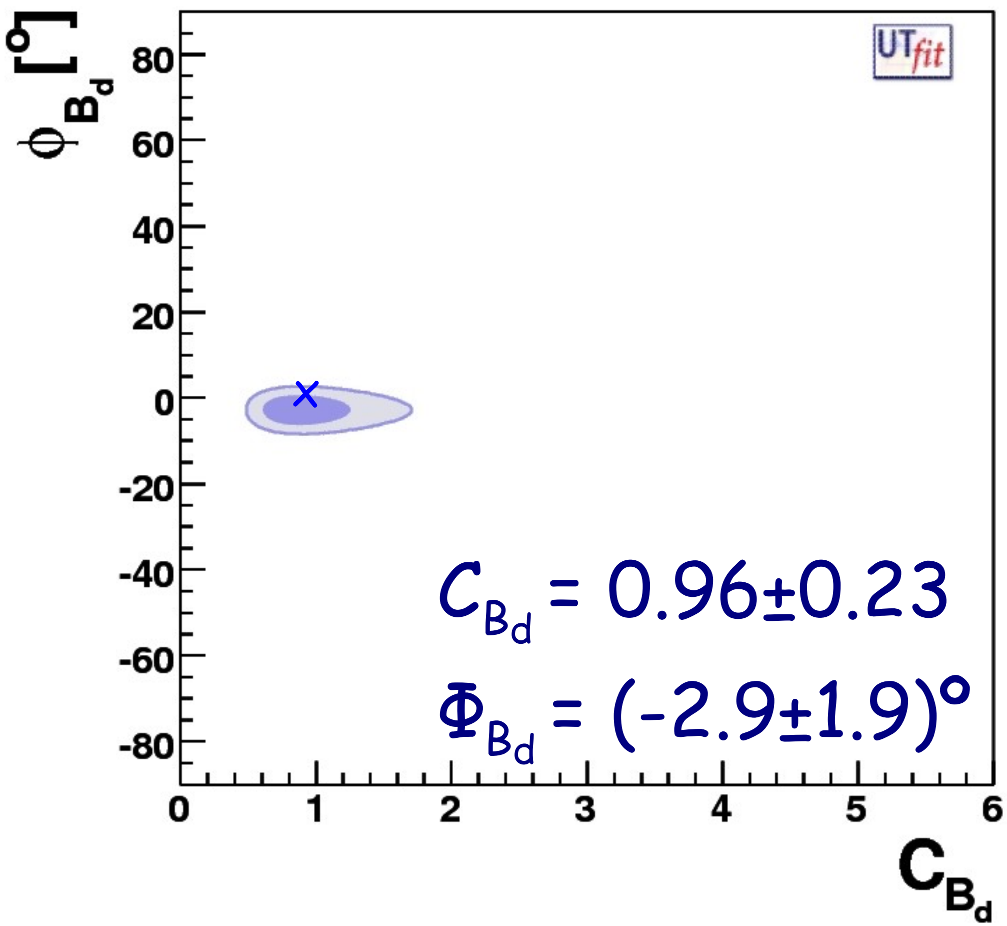
$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM} \qquad \varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

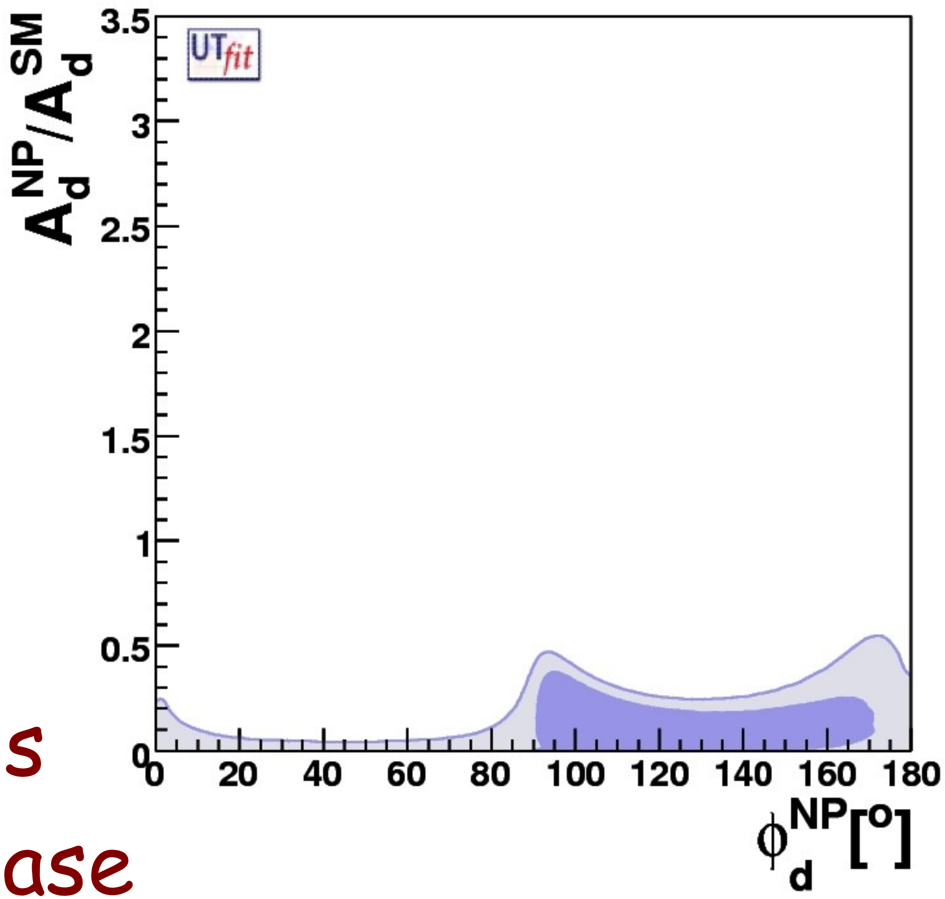
$$A_{CP}^{B_d \to J/\psi K_s} = \sin 2(\beta + \phi_{B_d}) \qquad B_s \to J/\psi\,\phi:\ \ f(-\beta_s + \phi_{B_s})$$

$$A_{SL}^q = \mathrm{Im}\left(\Gamma_{12}^q / A_q\right) \qquad \Delta\Gamma^q / \Delta m_q = \mathrm{Re}\left(\Gamma_{12}^q / A_q\right)$$

Results on the B_d mixing amplitude

* the sin2β "tension" produces nowadays a ~1.5σ effect in ϕ_{B_d} and the asymmetry in the $(A_d^{NP}/A_d^{SM},\ \phi_d^{NP})$ plane





* up to ~20% NP amplitude is allowed for generic NP phase

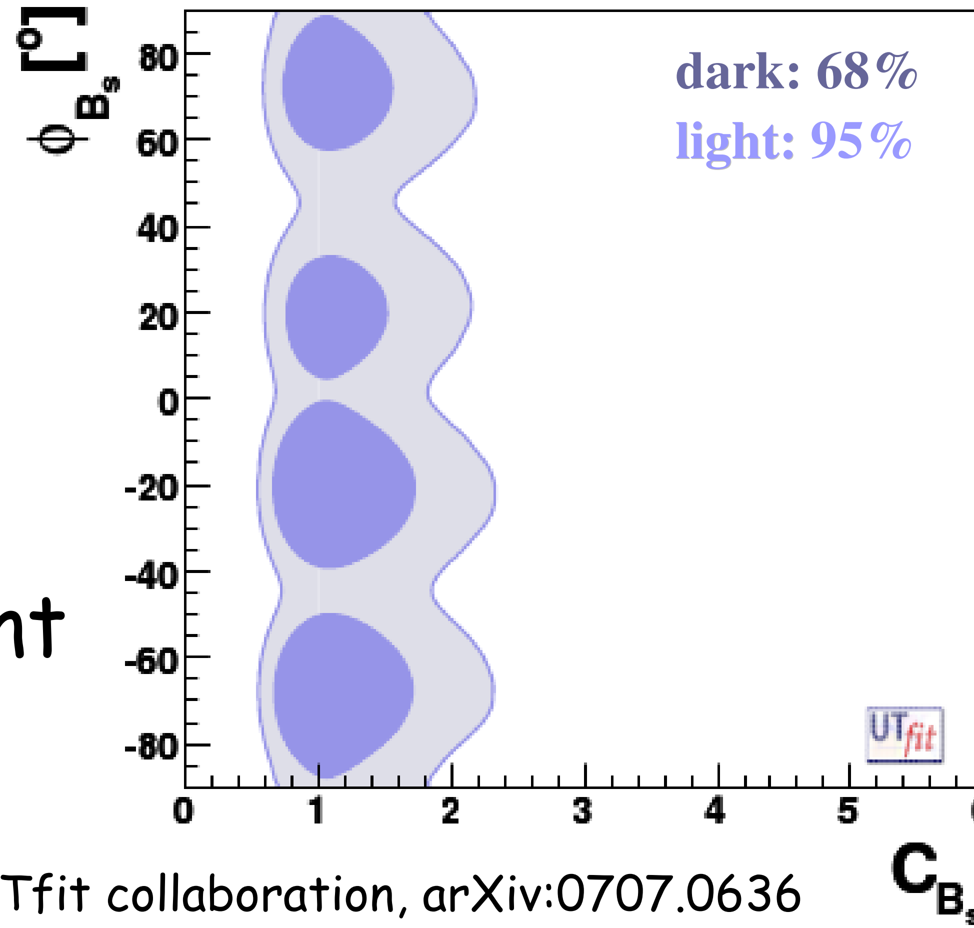
new physics in B_s mixing

the TeVatron realm

C_{B_s} = 1.11 ± 0.32

ϕ_{B_s} = (-69±14)° U (-20±14)° U (20±5)° U (72±8)°

* Δm_s
* $$\tau_{B_s}^{FS} = \frac{1}{\Gamma_s} \frac{1+\left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1-\left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$
* $A_{\rm SL}^s$
* $$A_{\rm SL}^{\mu\mu} = \frac{f_d \chi_{d0} A_{\rm SL}^d + f_s \chi_{s0} A_{\rm SL}^s}{f_d \chi_{d0} + f_s \chi_{s0}}$$
* $\Delta\Gamma_s$ and ϕ_s from the <u>untagged</u> time-dependent angular analysis of $B_s \to J/\Psi\ \phi$



UTfit collaboration, arXiv:0707.0636

Recently both CDF and DØ published the <u>tagged</u> time-dependent angular analysis of B_s -> J/Ψ ϕ

2D likelihood ratio for ΔΓ and ϕ_s

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

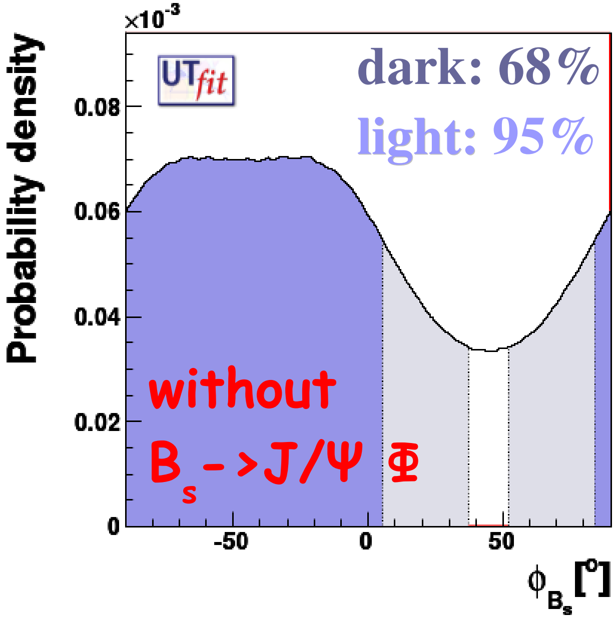
arXiv:0712.2397

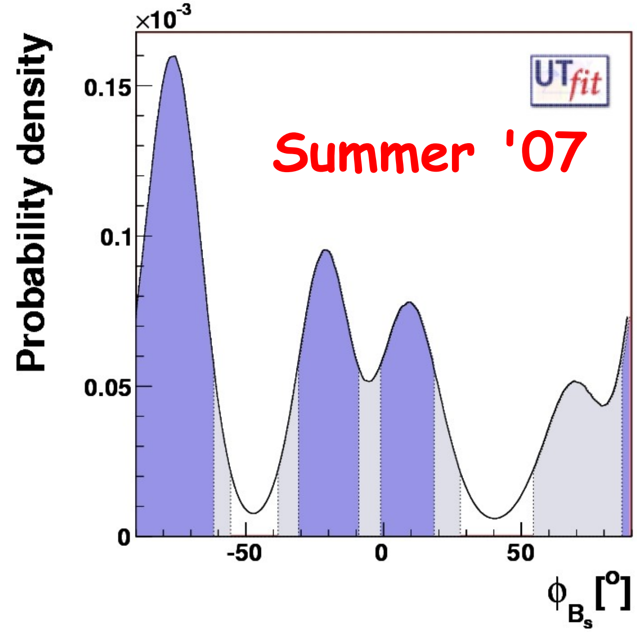
7-parameter fit + correlation matrix or 1D likelihood profiles of ΔΓ and ϕ_s

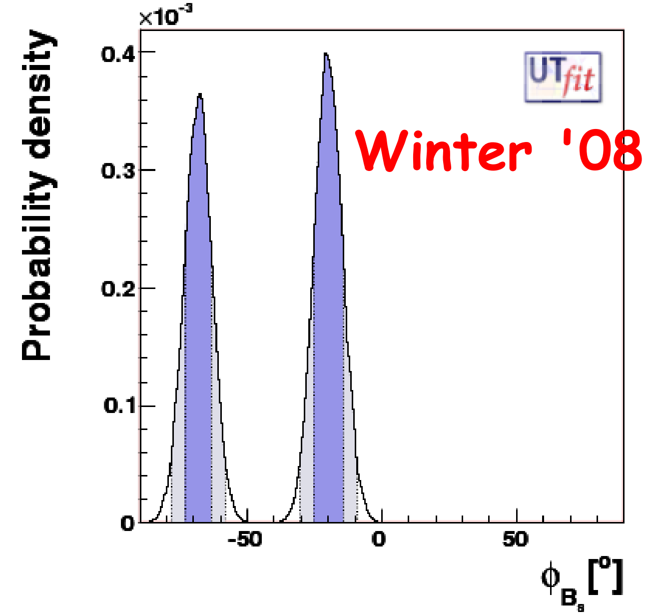
2-fold ambiguity removed using strong phases from B -> J/Ψ K* + SU(3) + ?

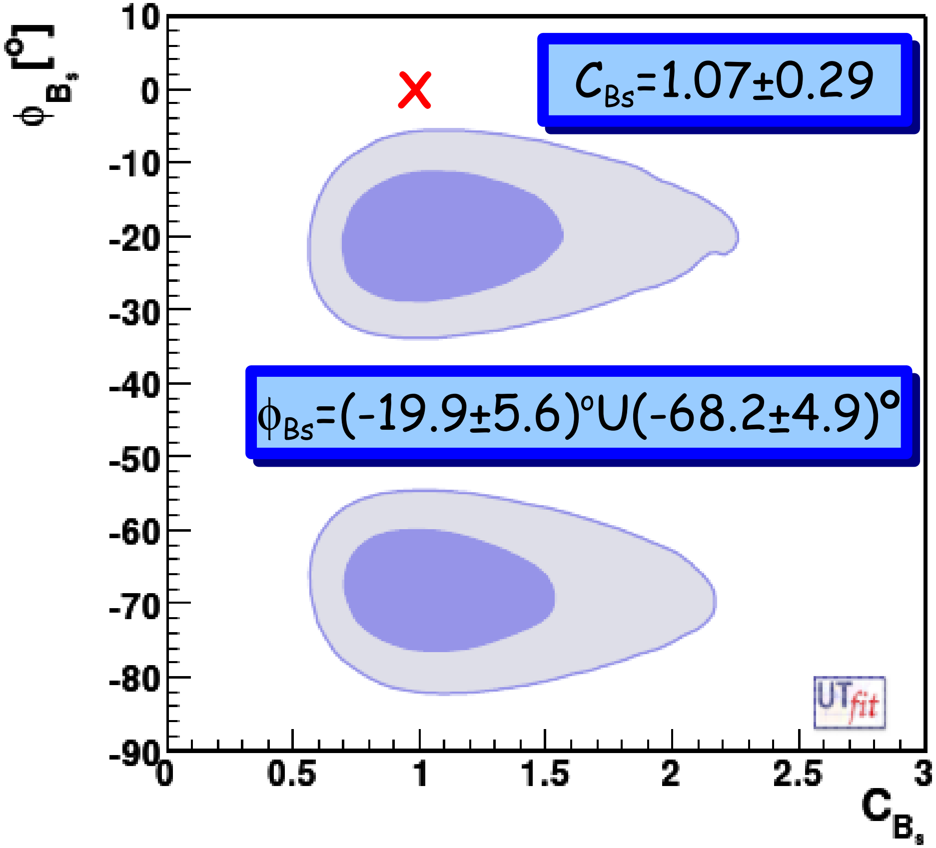
arXiv:0802.2255

Combining the two measurements requires some gymnastic with the DØ results...



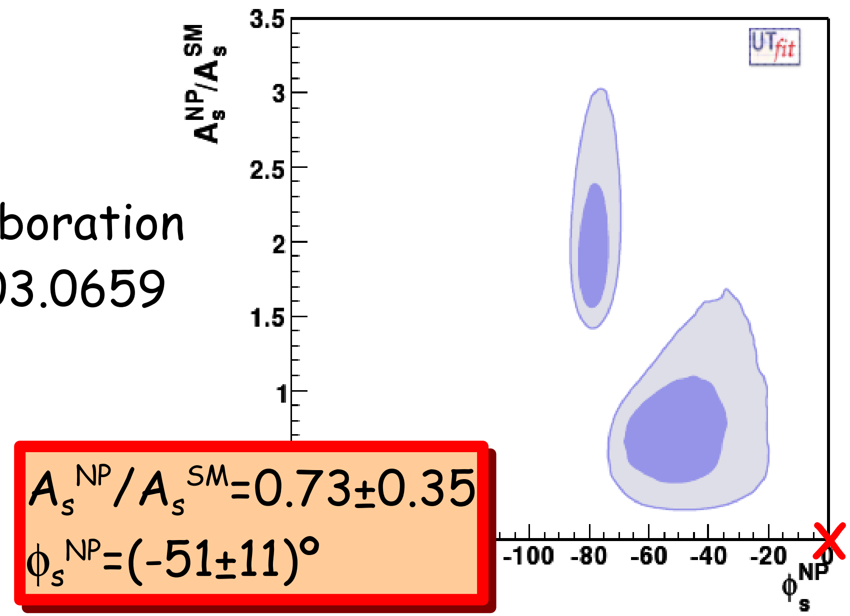






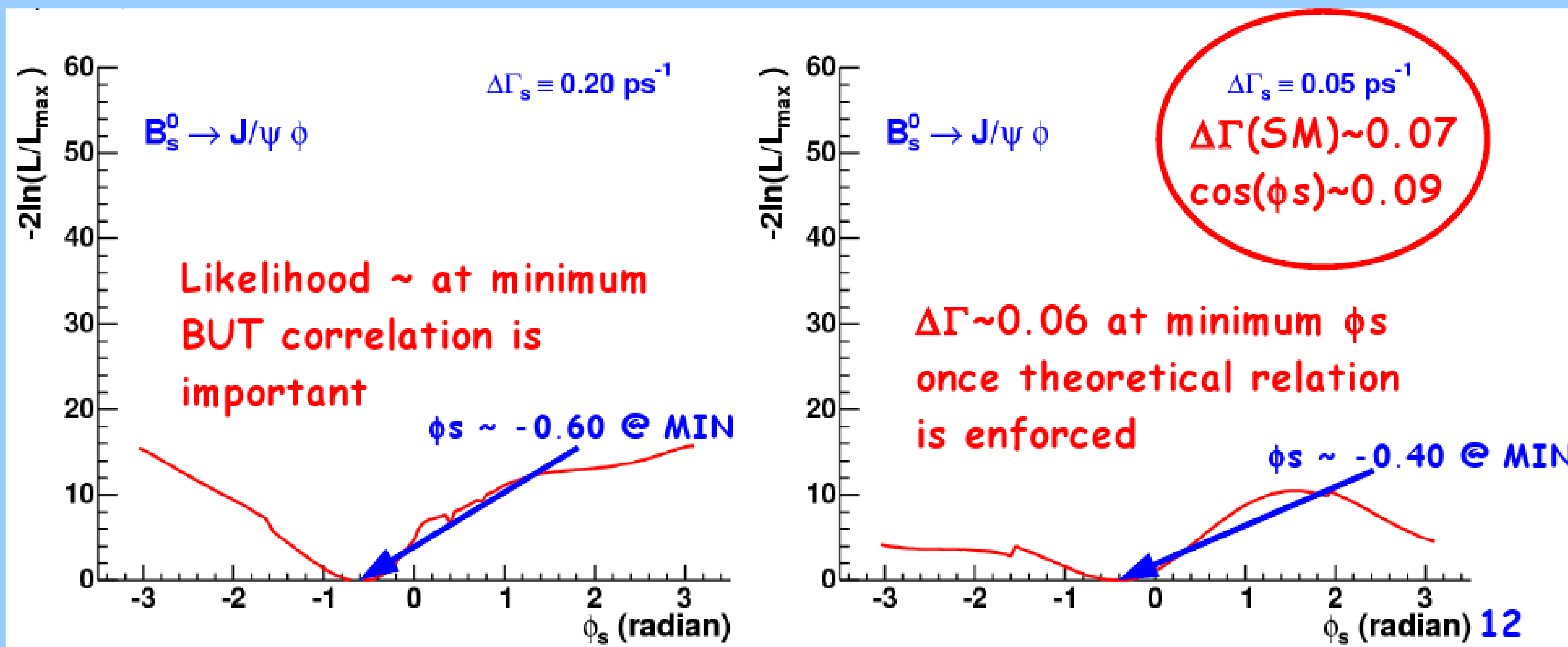
ϕ_{Bs} < 0 @99.7% probability
(equivalent to the Gaussian 3σ level)
for any treatment of the DØ data

UTfit collaboration
arXiv:0803.0659



ICHEP '08 update (i)

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



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)

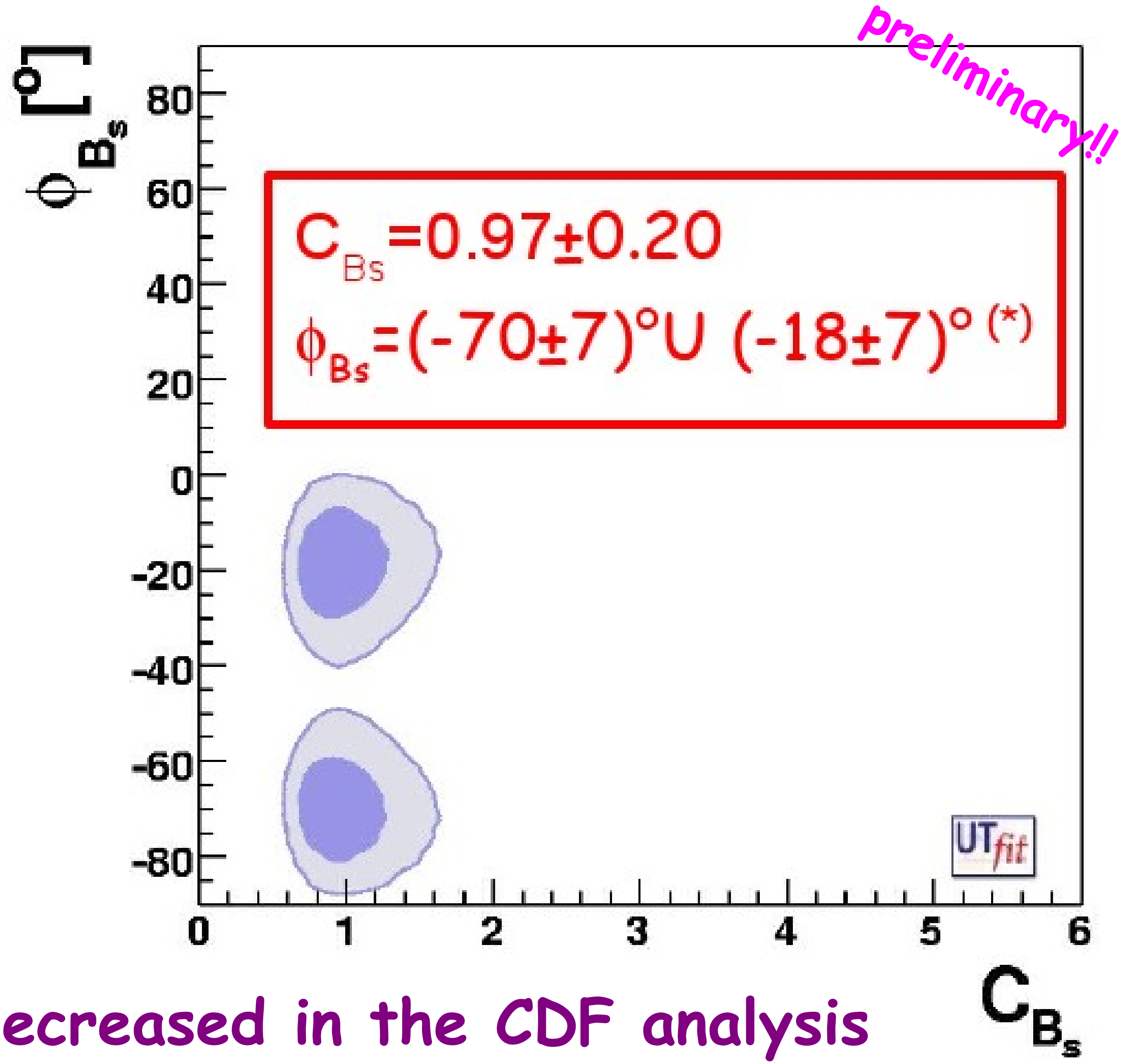
ICHEP '08 update (ii)

Including the reanalysis of the DØ data

(*) $\phi_{Bs} < 0$:

$3\sigma \rightarrow 2.5\sigma$

New CDF data not included: new CDF likelihood "not ready yet"



SM compatibility decreased in the CDF analysis

If this evidence is confirmed...

* 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 in SUSY-GUTs
* In progress: (i) update of the $\Delta F=2$ EFT analysis, (ii) correlations with $\Delta F=1$ in the MSSM

2. the ΔF=2 effective Hamiltonian

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

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

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

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

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

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

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

7 new operators beyond SM/CMFV involving quarks with different chiralities

H_{eff} can be recast in terms of the high-scale $C_i(\Lambda)$

- $C_i(\Lambda)$ can be extracted from the data (one by one)
- the associated NP scale Λ can be defined as

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

tree/strong interact. NP: $L \sim 1$

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

Flavour structures:

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 (TeV @95%)

B + K

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

B only (pre-Tevatron)

strong/tree	α_s loop	α_W loop
–	–	–
14	1.4	0.4
2200	220	66

* $\Delta F=2$ chirality-flipping operators are RG enhanced and thus probe larger NP scales
* when these operators are allowed, the NP scale is easily pushed beyond the LHC reach (manifestation of the flavour problem)
* suppression of the 1 <-> 2 transitions strongly weakens the lower bound on the NP scale

preliminary

Upper bound on the NP scale

In the presence of a NP evidence
the EFT analysis also gives an
UPPER bound on the NP scale (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 the flavour couplings
cannot be general nor SM-like

MSSM + generic soft SUSY-breaking terms

All flavour-changing NP effects in the squark propagators

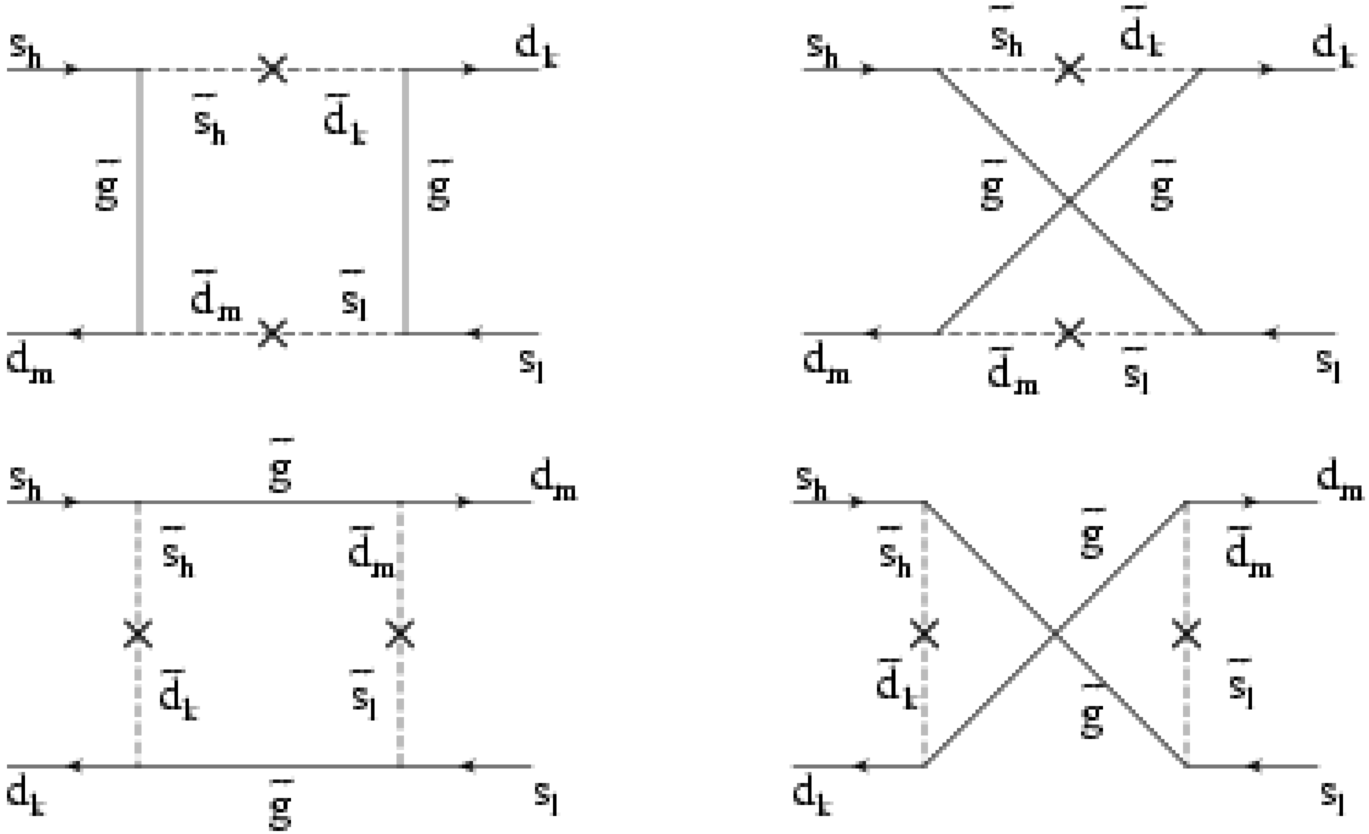
$$(\tilde q_i)_A \; - - - \times - - - \; (\tilde q_j)_B \qquad (\delta^q_{ij})_{AB}$$

$$q = \{u, d\}, \quad (A, B) = \{L, R\}$$

$$(i, j) = \{1, 2, 3\}$$

- NP scale: SUSY masses $\widetilde{m} \sim m_{\tilde g}$
- flavour-violating couplings: $(\delta^q_{ij})_{AB} \equiv \dfrac{(M^2_{ij})^q_{AB}}{\widetilde{m}^2}$

$$(M^2)^{\tilde d} = \begin{pmatrix} m^2_{\tilde d_L} & m_d(A_d - \mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde d_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde s_L} & m_s(A_s - \mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde s_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde b_L} & m_b(A_b - \mu\tan\beta) \\ & & & & & m^2_{\tilde b_R} \end{pmatrix}$$



trivial changes in the case ΔB=2

dominant gluino-squark contributions to the Wilson coefficients

$$C_1 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{LL}^2 f_1(x) \quad C_2 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{RL}^2 f_2(x) \quad C_3 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{RL}^2 f_3(x)$$

$$\tilde{C}_1 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{RR}^2 f_1(x) \quad \tilde{C}_2 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{LR}^2 f_2(x) \quad \tilde{C}_3 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{LR}^2 f_3(x)$$

$$C_4 = \frac{\alpha_s^2}{\tilde{m}^2}\left[(\delta_{12}^d)_{LL}(\delta_{12}^d)_{RR} f_4(x) + (\delta_{12}^d)_{LR}(\delta_{12}^d)_{RL} \tilde{f}_4(x)\right]$$

$$C_5 = \frac{\alpha_s^2}{\tilde{m}^2}\left[(\delta_{12}^d)_{LL}(\delta_{12}^d)_{RR} f_5(x) + (\delta_{12}^d)_{LR}(\delta_{12}^d)_{RL} \tilde{f}_5(x)\right]$$

Gabbiani et al., hep-ph/9604387

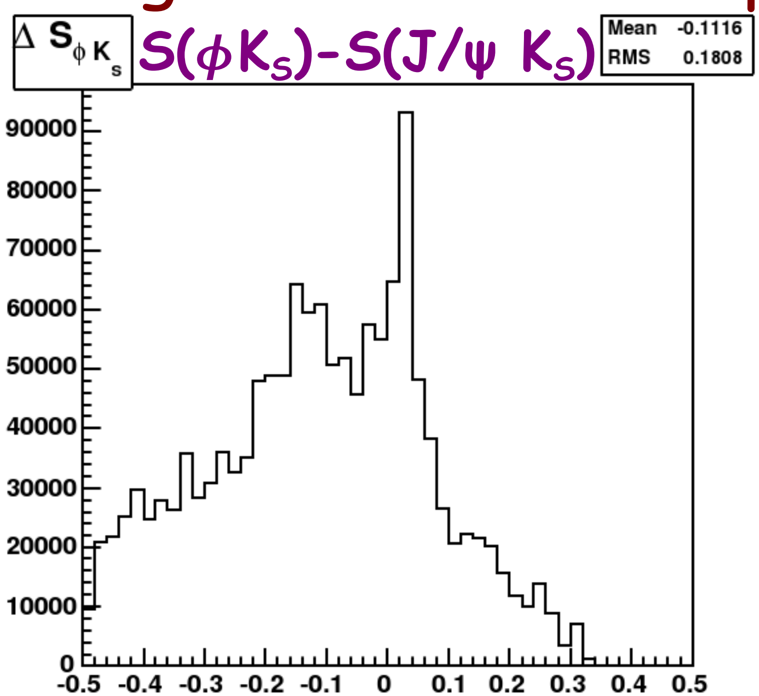
* chirality-flipping mass insertions are strongly bounded by $b \to s\,\gamma$: they are too small to produce the measured ϕ_s

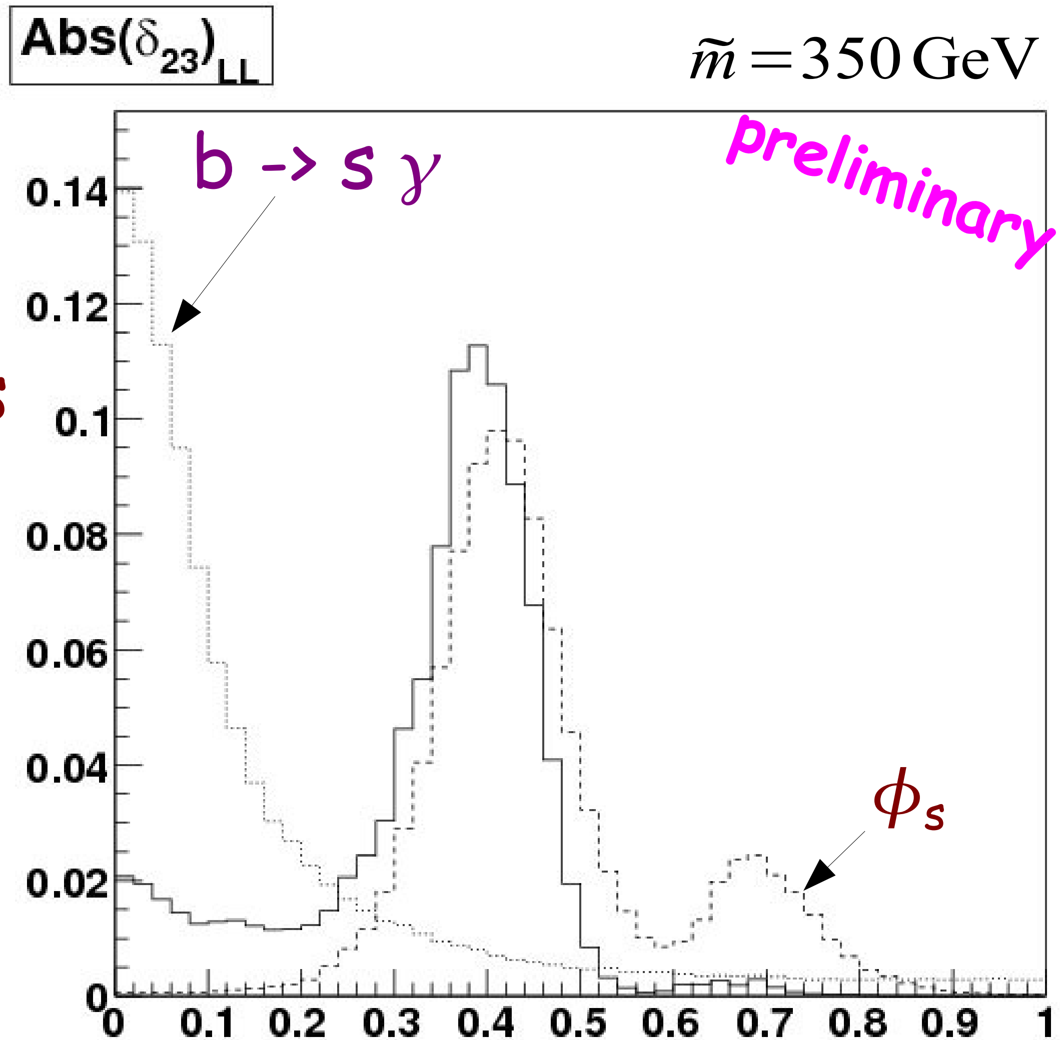
case #1: single mass insertion, e.g. $(\delta_{23})_{LL}$

* large MI needed for ϕ_s: tension with $b \to s\,\gamma$

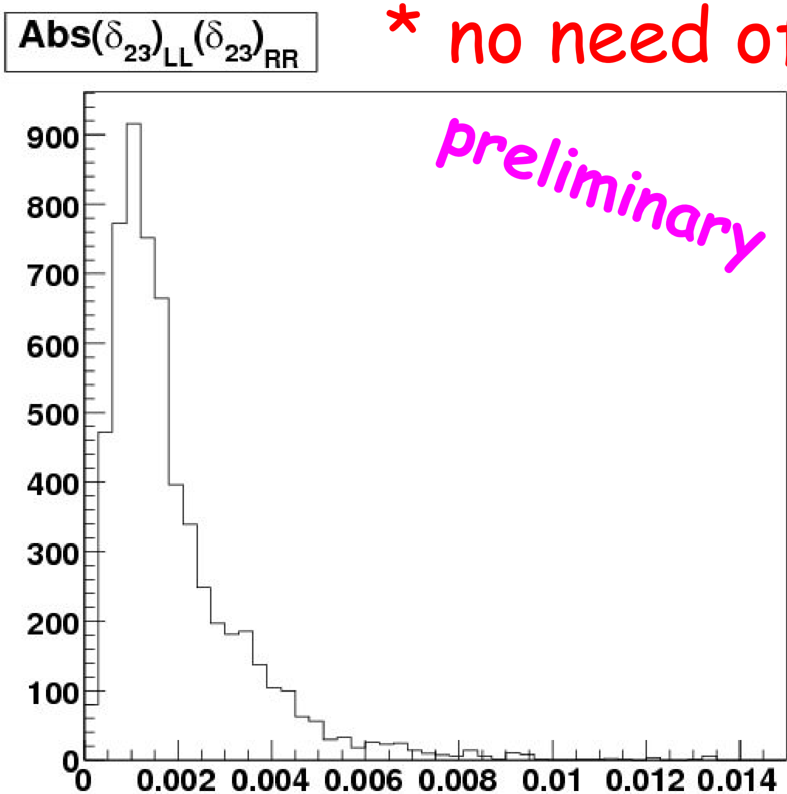
* MI saturates at 1: upper bound $\tilde{m}$ < O(1 TeV)

* huge effect in b->s penguins



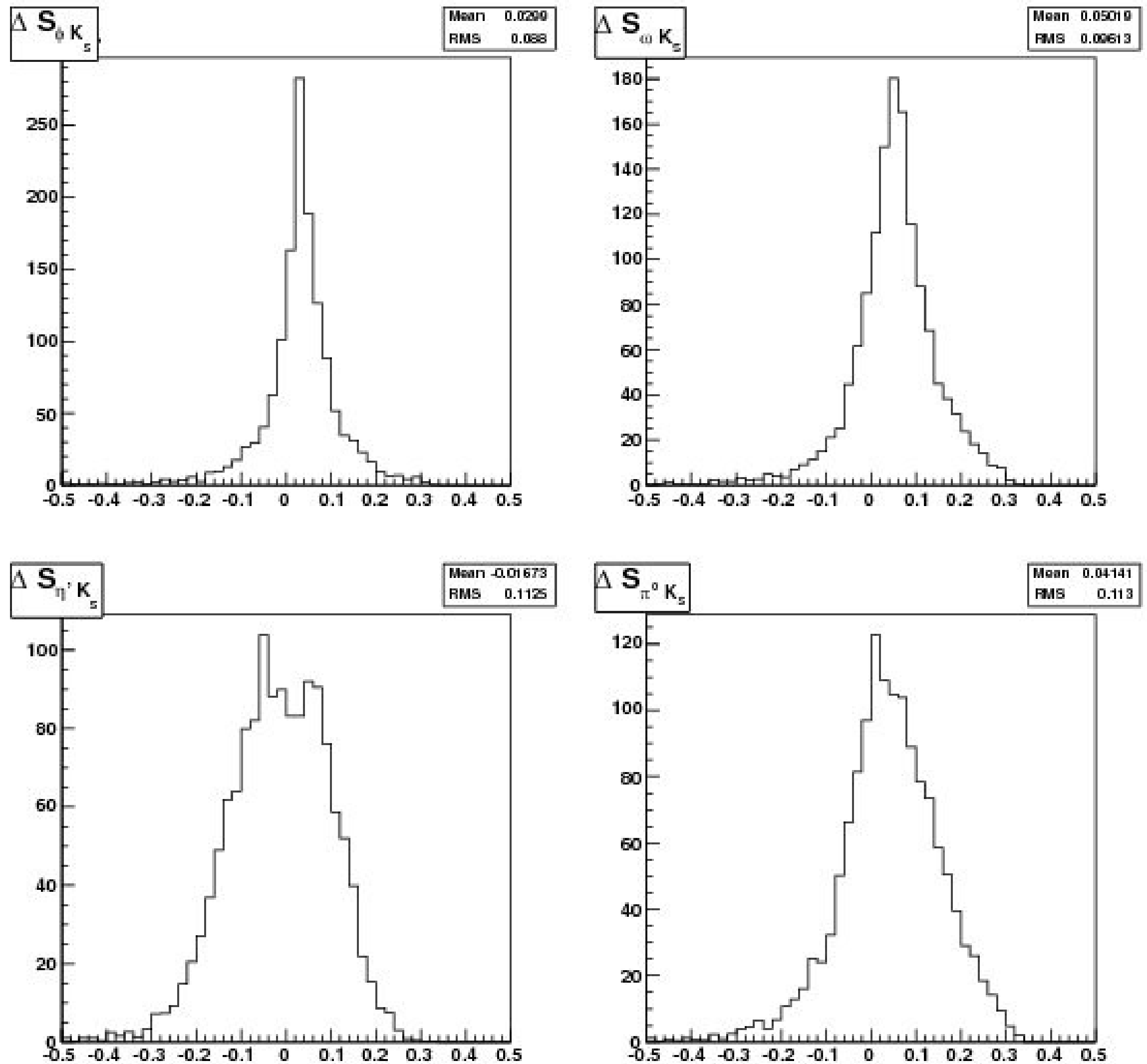


case #2: double mass insertion, $(\delta_{23})_{LL}$ & $(\delta_{23})_{RR}$



* no need of large MIs: $(\delta_{23})_{LL} \sim (\delta_{23})_{RR} \sim 3\text{-}4 \cdot 10^{-2}$

b -> s γ is no longer a problem



* large effects in b->s penguins still possible (larger if LR MIs are also switched on)

SUSY-GUTs: $b \to s$ vs $\tau \to \mu$

If SUSY is broken at a scale larger than M_{GUT}, squark and slepton masses unify, including off-diagonal terms i.e. δs

The following relations hold at M_Z:

$$(\delta^d_{ij})_{RR} \simeq \frac{m^2_L}{m^2_D} (\delta^l_{ij})_{LL}$$

$$(\delta^{u,d}_{ij})_{LL} \simeq \frac{m^2_E}{m^2_Q} (\delta^l_{ij})_{RR}$$

$$(\delta^u_{ij})_{RR} \simeq \frac{m^2_E}{m^2_U} (\delta^l_{ij})_{LL}$$

$$(\delta^d_{ij})_{LR} \simeq \frac{m^2_{L_{ave}}}{m^2_{Q_{ave}}} \frac{m_b}{m_\tau} (\delta^l_{ij})^*_{RL}$$

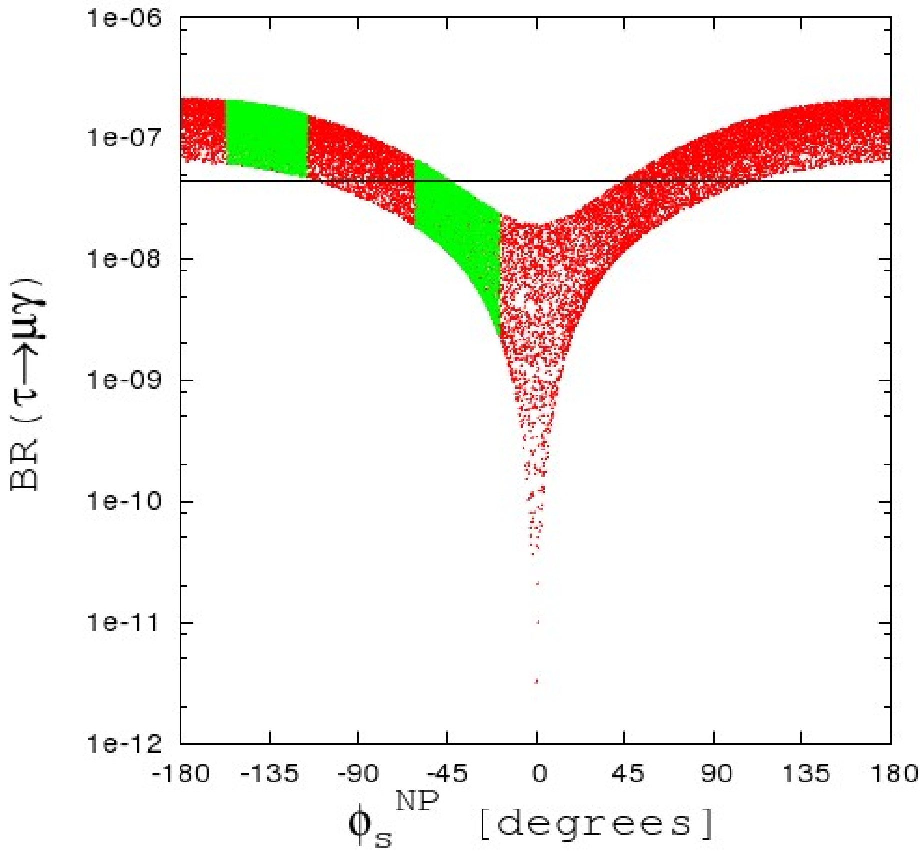
MC et al., hep-ph/0307191

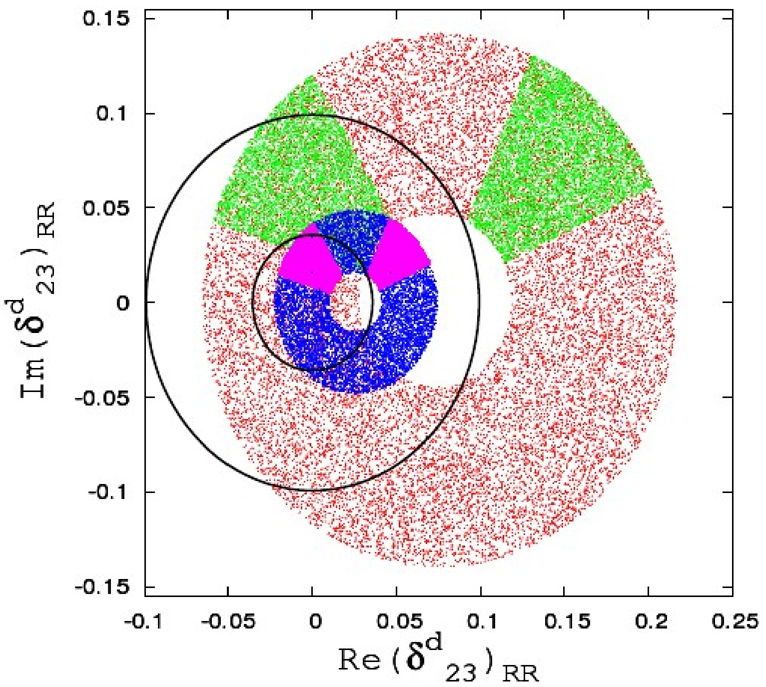
Lower bound on τFV in SUSY-GUT's

Parry, Zhang, arXiv:0710.5443v2

mass insertion analysis in a SUSY-GUT scheme

- * RG-induced $(\delta_{23})_{LL}$
- * explicit $(\delta_{23})_{RR}$

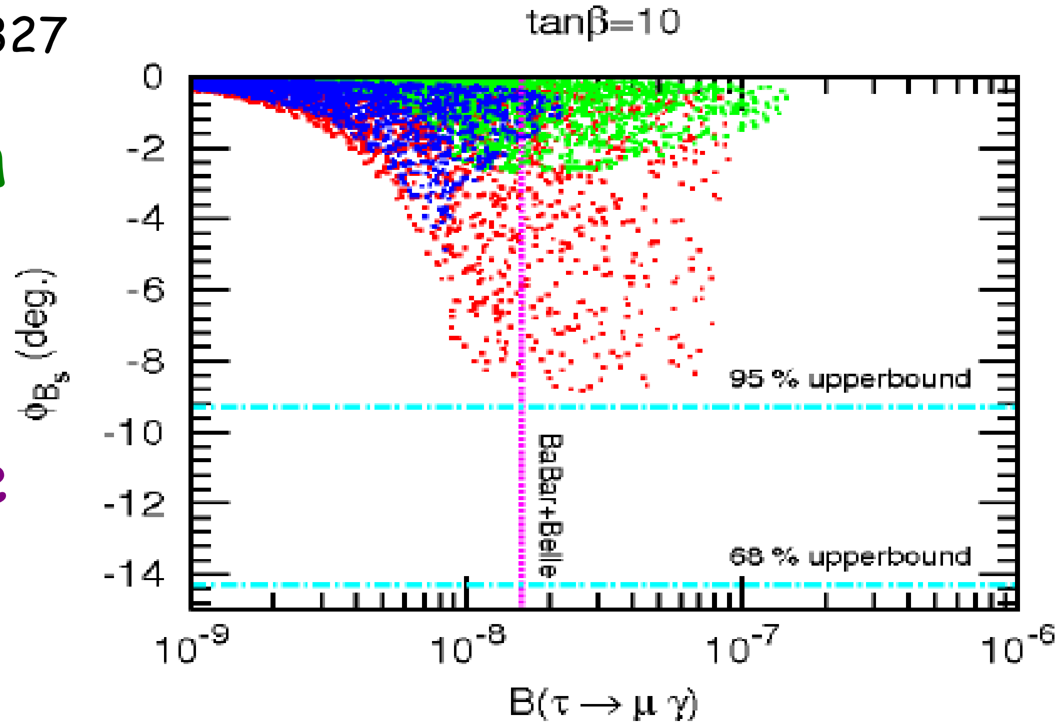




In the UTfit range for the B_s mixing phase:

$$BR(\tau \to \mu\gamma) > 3 \times 10^{-9} \text{ !!}$$

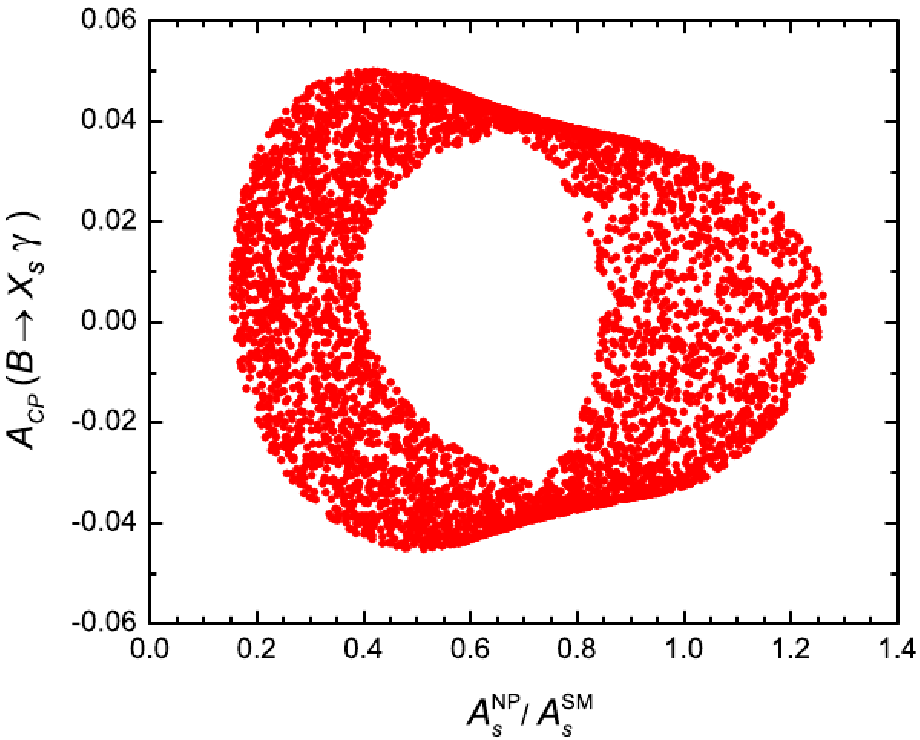
Hisano, Shimizu, arXiv:0805.3327



In a SU(5) SUSY-GUT with ν_R and supergravity-like boundary conditions:

large φ_s requires too large BR($\tau \to \mu\gamma$): marginal !!!

Dutta, Mimura, arXiv:0805.2988



Enlarging the GUT group to SO(10), the correlation φ_s-BR($\tau \to \mu\gamma$) can be relaxed

large φ_s correspond to large CP asymmetries in B → $X_s\ \gamma$

Conclusions

The new UTfit combination of the Tevatron data gives a 2.5σ deviation of Φ_s from the SM (new CDF measurement still to be included)

If confirmed, the SM but also NP flavour patterns like MFV and NMFV are ruled out

A large Φ_s in the MSSM can be generated by double chirality-conserving 2-3 MI's ~10^{-2}

In simplest SU(5) SUSY-GUTs large Φ_s can be correlated to (too) large $BR(\tau \to \mu\gamma)$

Spare Slides

Time-dependent angular analysis

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

Dunietz, Fleischer, Nierste
hep-ph/0012219

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

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

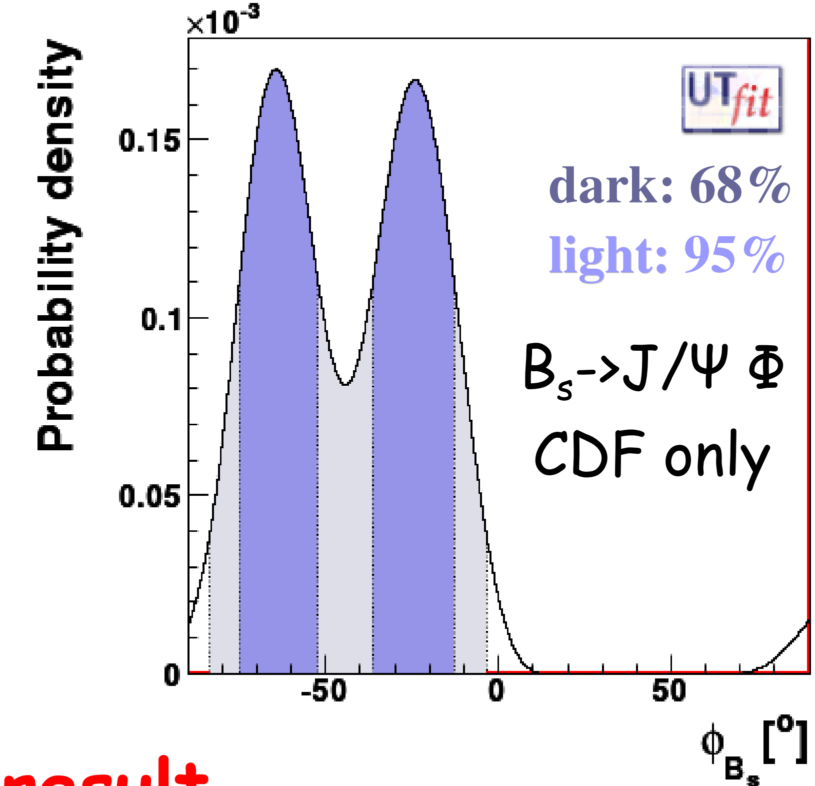
$$|A_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma t}\left[\cosh\frac{\Delta\Gamma\,t}{2} - |\cos\phi|\sinh\frac{|\Delta\Gamma|\,t}{2} + \sin\phi\,\sin(\Delta m\,t)\right]$$

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

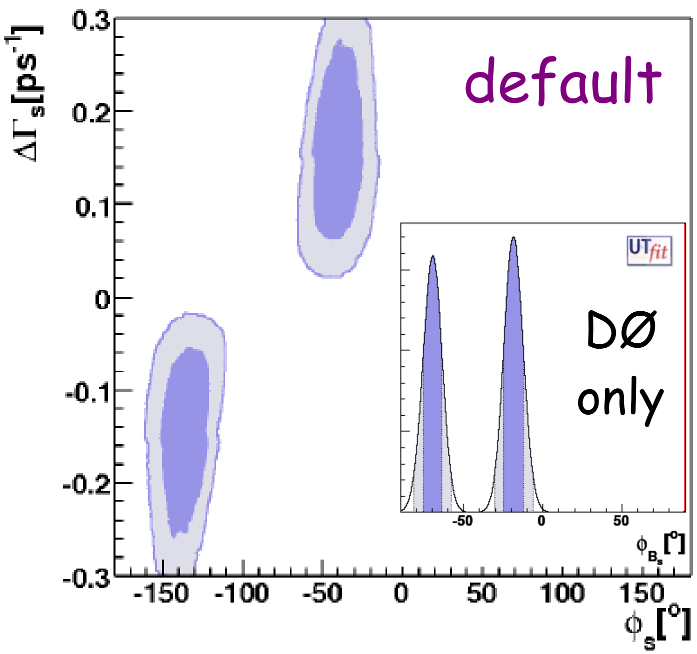
$$\mathrm{Im}\,\{A_0^*(t)A_\perp(t)\} = |A_0(0)|\,|A_\perp(0)|\,e^{-\Gamma t}$$
$$\times\left[\sin\delta_2\,\cos(\Delta m\,t) - \cos\delta_2\,\cos\phi\,\sin(\Delta m\,t) - \cos\delta_2\,\sin\phi\,\sinh\frac{\Delta\Gamma\,t}{2}\right]$$

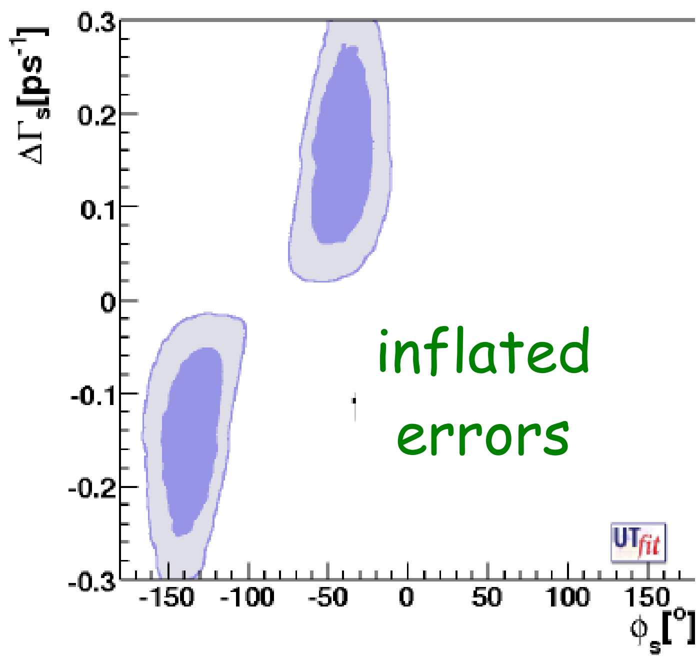
$$\mathrm{Im}\,\{\overline{A}_0^*(t)\overline{A}_\perp(t)\} = |A_0(0)|\,|A_\perp(0)|\,e^{-\Gamma t}$$
$$\times\left[-\sin\delta_2\,\cos(\Delta m\,t) + \cos\delta_2\,\cos\phi\,\sin(\Delta m\,t) - \cos\delta_2\,\sin\phi\,\sinh\frac{\Delta\Gamma\,t}{2}\right]$$

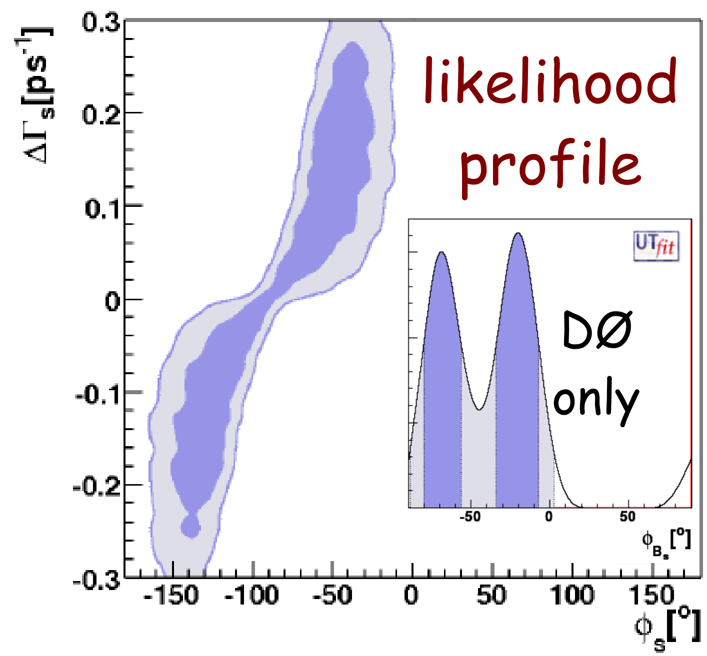
* default: CDF likelihood+Gaussian DØ result with 2x2 corr. matrix
* inflated error: as above, but with error inflated to reproduce the 2σ range computed by DØ
* likelihood profile: using the 1D likelihood profiles for ϕ_s and $\Delta\Gamma_s$



ambiguity reintroduced in the DØ result







UT parameters in the presence of NP

Model-independent fit of the CKM parameters
(neglecting NP in tree decays)

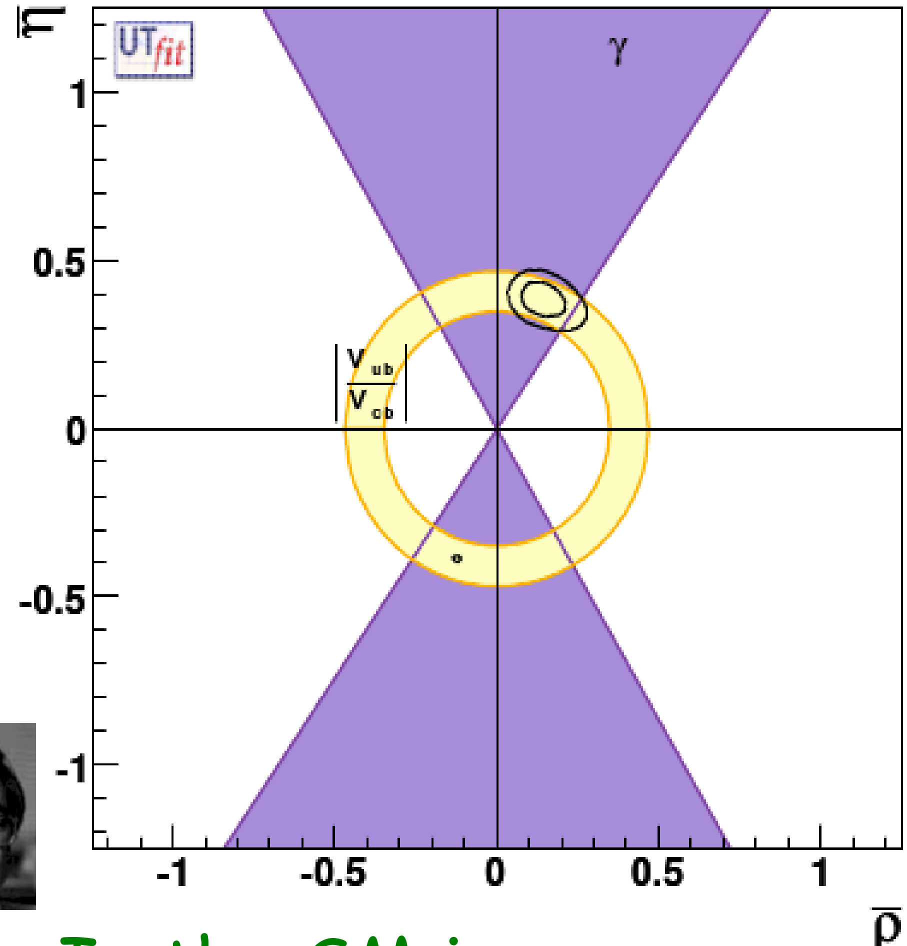
$$V_{CKM} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

λ = 0.2258 ± 0.0014

A = 0.804 ± 0.001

$\bar{\rho}$ = 0.140 ± 0.046

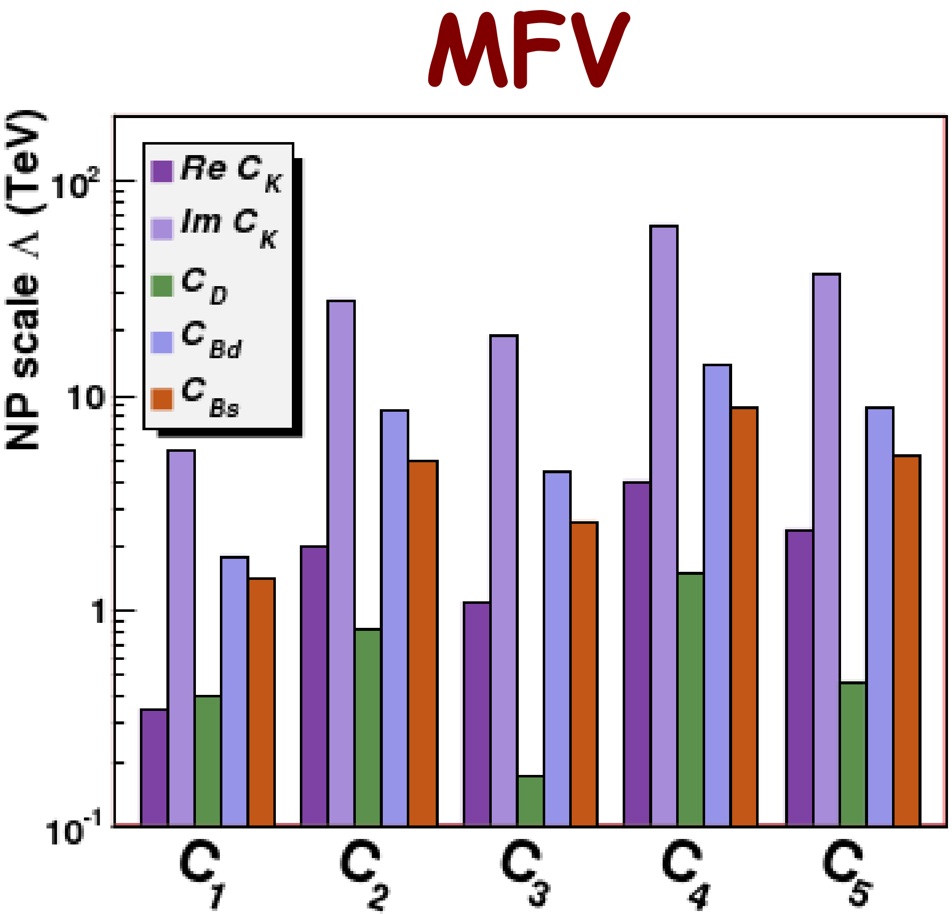
$\bar{\eta}$ = 0.384 ± 0.035

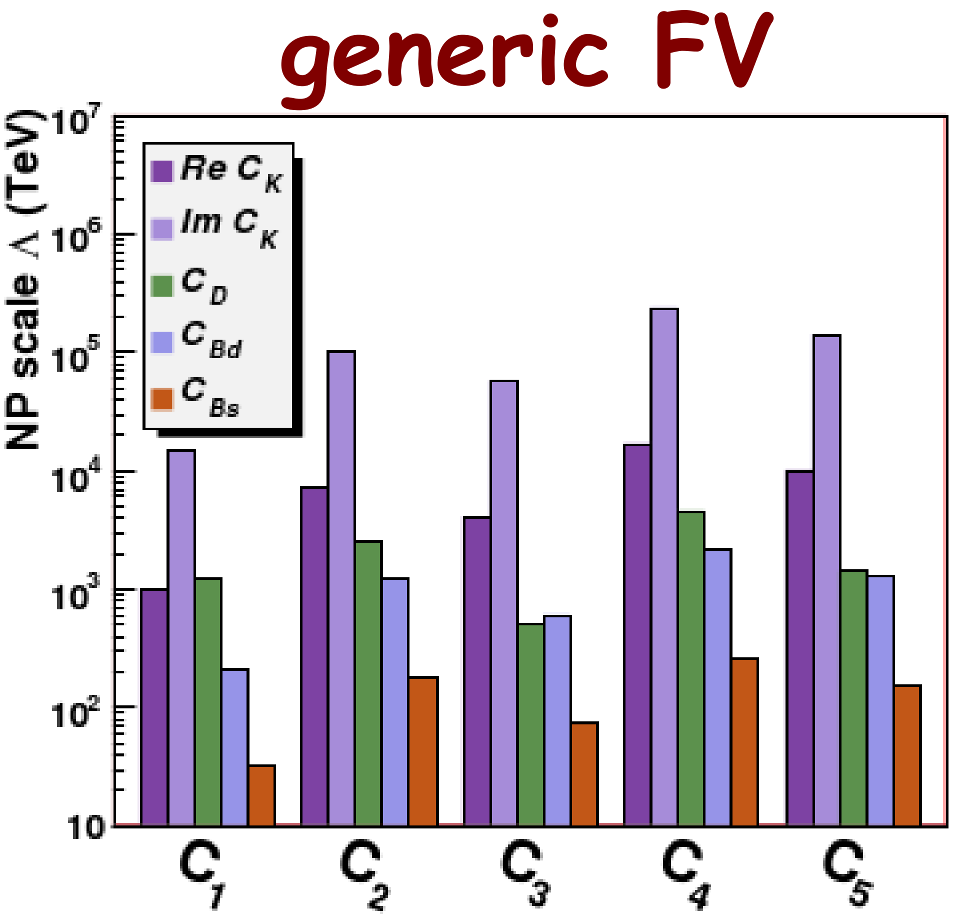


In the SM is:

$\bar{\rho}$ = 0.147 ± 0.029

$\bar{\eta}$ = 0.342 ± 0.012





Contributions of the ΔF=2 operators to the lower bound on the NP scale in the tree/strong interacting case