

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
and M. Pierini's TH seminar

* 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

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):

$$\text{Re } A_K = C_{\Delta m_K} \text{Re } A_K^{SM} \quad \text{Im } A_K = C_\varepsilon \text{Im } A_K^{SM}$$

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

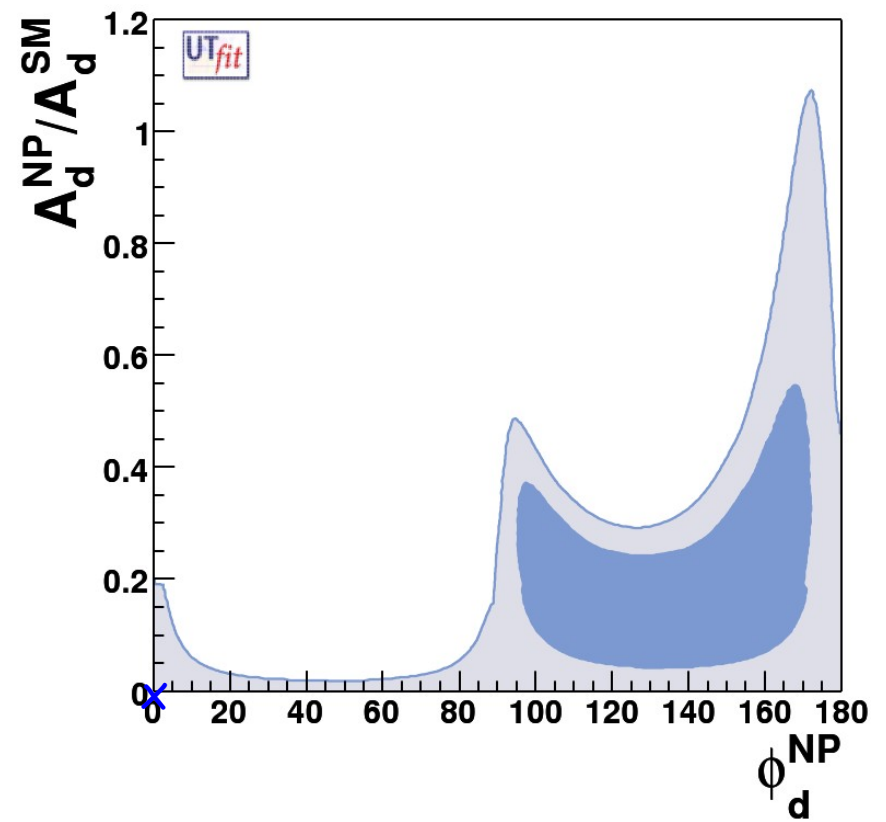
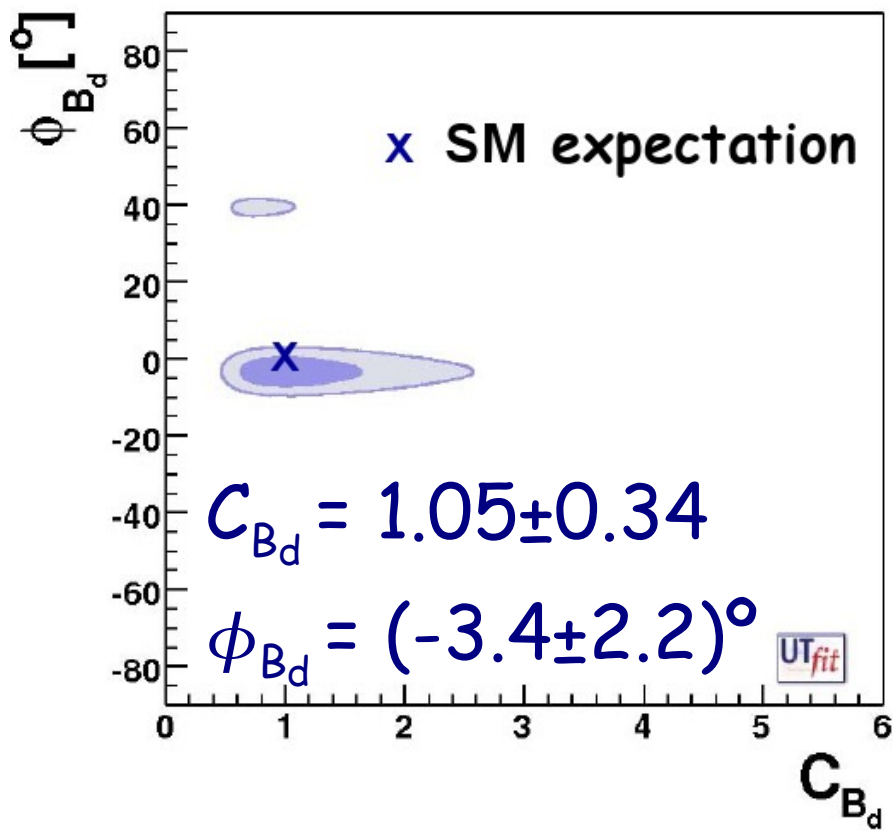
$$A_q e^{2i\phi_q} = C_{B_q} e^{2i\phi_{B_q}} A_q^{SM} e^{2i\phi_q^{SM}} = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_q^{NP} - \phi_q^{SM})} \right) A_q^{SM} e^{2i\phi_q^{SM}}$$

Observables:

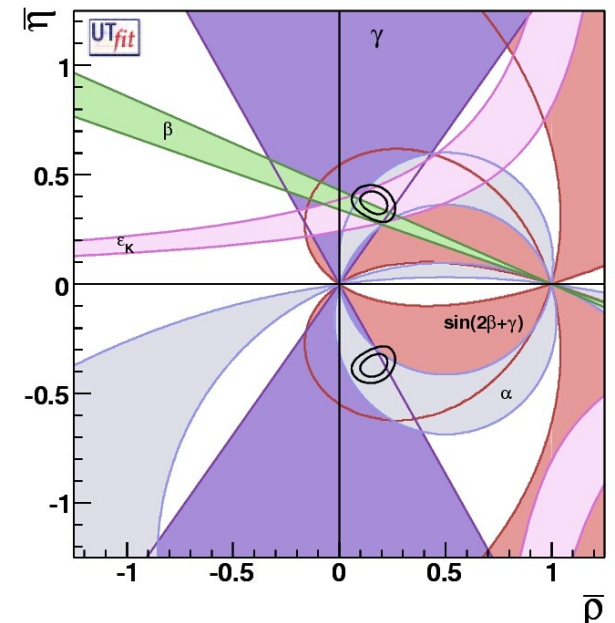
$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM} \quad \varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

$$A_{CP}^{B_d \rightarrow J/\psi K_s} = \sin 2(\beta + \phi_{B_d}) \quad A_{CP}^{B_s \rightarrow \phi K_s} = \sin 2(-\beta_s + \phi_{B_s})$$

$$A_{SL}^q = \text{Im}(\Gamma_{12}^q / A_q) \quad \Delta \Gamma^q / \Delta m_q = \text{Re}(\Gamma_{12}^q / A_q)$$



- * the $\sin 2\beta$ tension produces the 1.5σ effect of ϕ_{B_d} and the asymmetry in $(A_d^{NP}/A_d^{SM}, \phi_d^{NP})$
- * up to $\sim 20\%$ NP amplitude is allowed for generic NP phase



new physics in B_s mixing



the TeVatron realm



$$C_{B_s} = 1.11 \pm 0.32$$

$$\phi_{B_s} = (-69 \pm 14)^\circ \cup (-20 \pm 14)^\circ \\ \cup (20 \pm 5)^\circ \cup (72 \pm 8)^\circ$$

* Δm_s

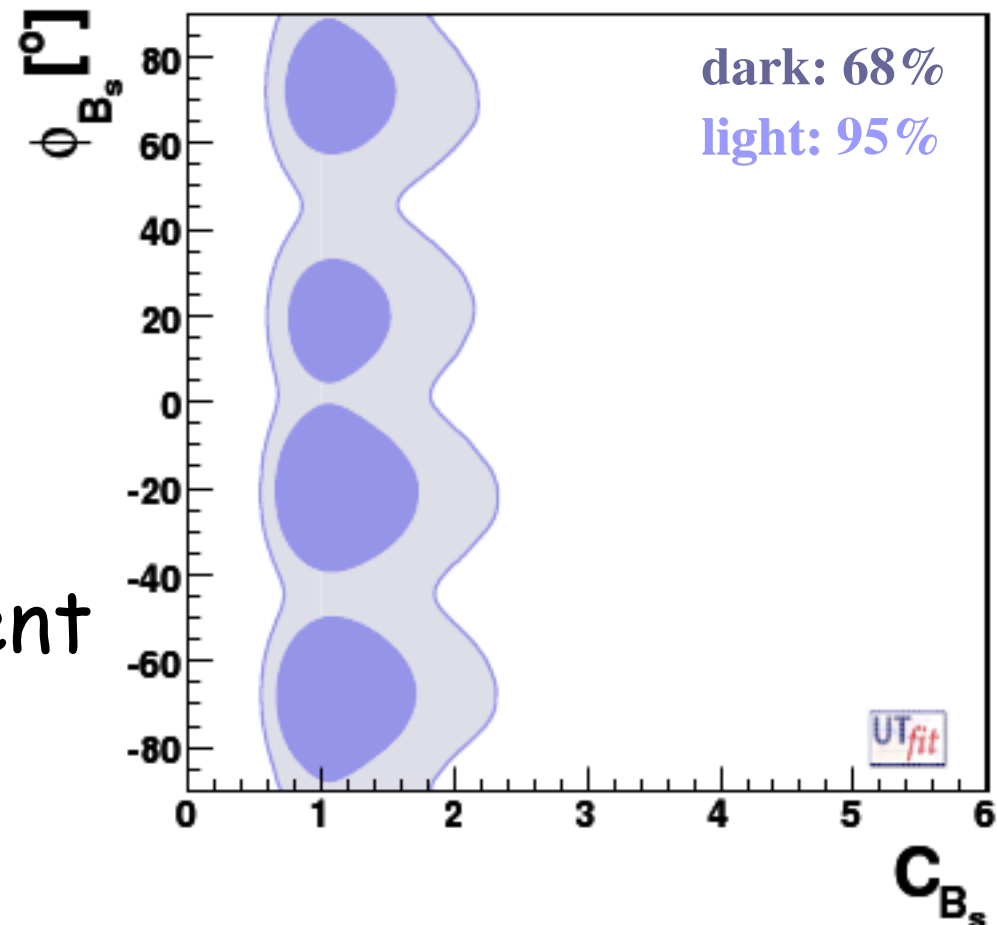
* $\tau_{B_s}^{FS} = \frac{1}{\Gamma_s} \frac{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$

* A_{SL}^s

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

* $\Delta\Gamma_s$ and ϕ_s from the untagged time-dependent angular analysis of

$$B_s \rightarrow J/\psi \phi$$



Recently 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

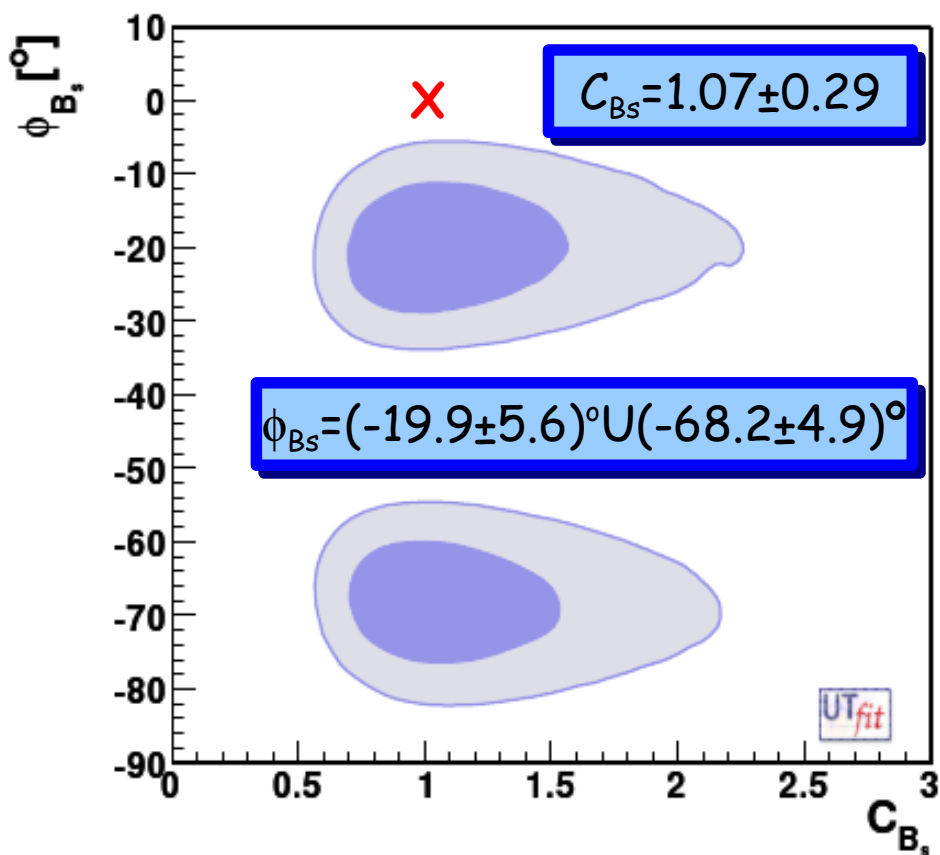
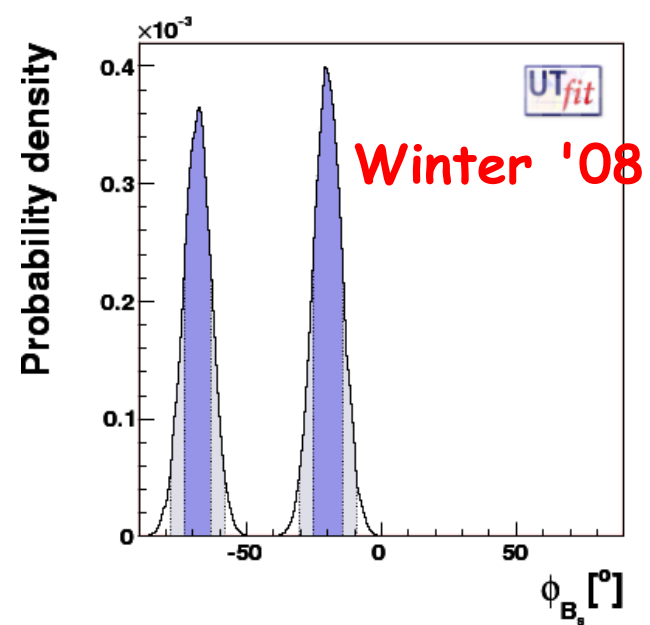
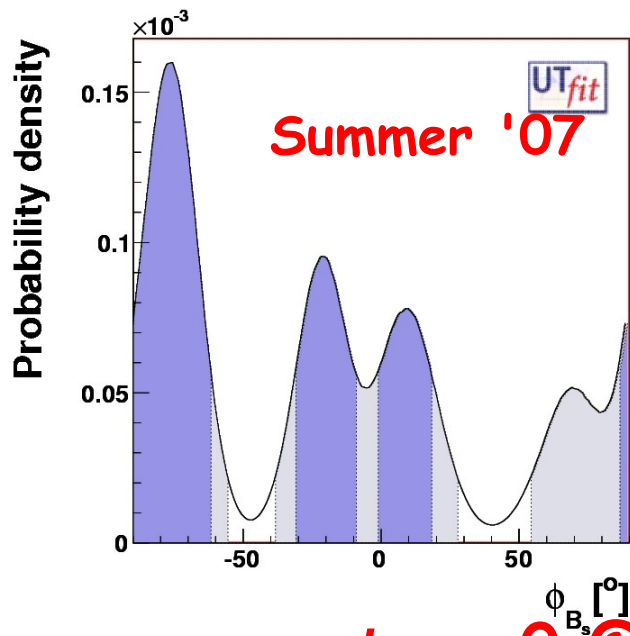
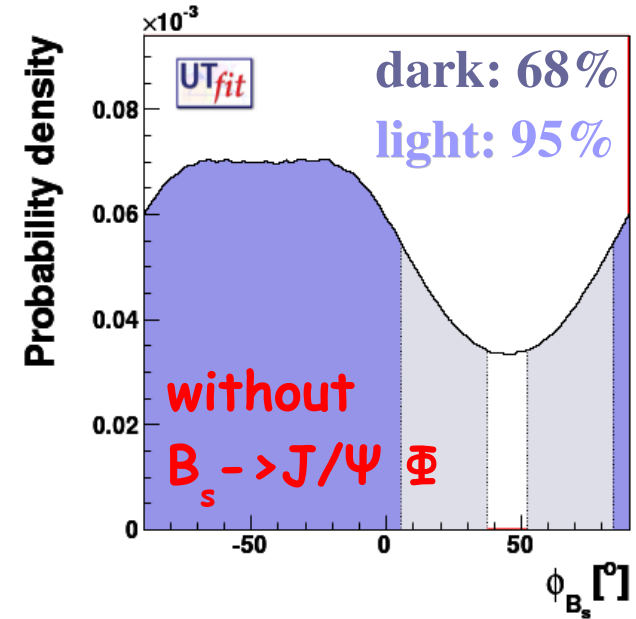
arXiv:0712.2397



7-parameter fit + correlation matrix
or 1D likelihood profiles of $\Delta\Gamma$ and ϕ_s
2-fold ambiguity removed using strong phases from $B \rightarrow J/\psi K^* + SU(3) + ?$

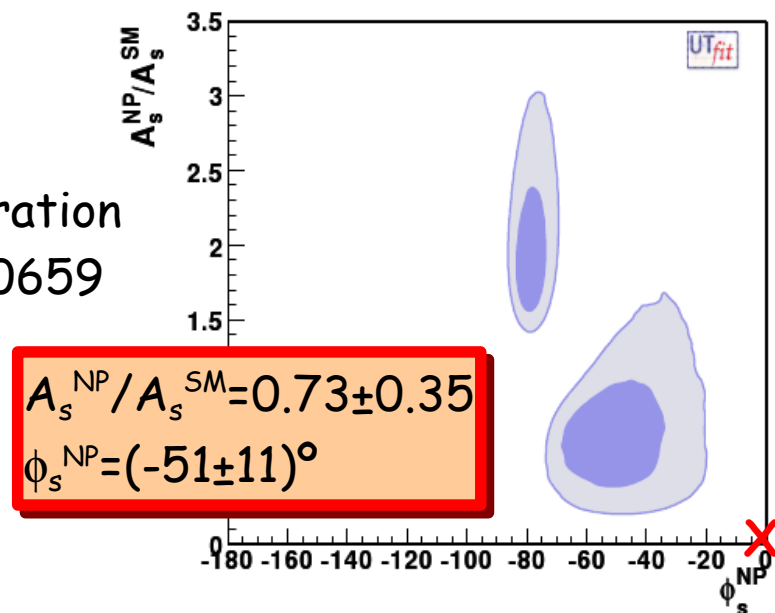
arXiv:0802.2255

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



$\phi_{B_s} < 0$ @99.7% probability
(equivalent to the Gaussian 3σ level)
for any treatment of the D^0 data

UTfit collaboration
arXiv:0803.0659



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 \leftrightarrow 2: strong suppression

1 \leftrightarrow 3: $\leq O(10\%)$

2 \leftrightarrow 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 $\Delta F=2$ effective Hamiltonian

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

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

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

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

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

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

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

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

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

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

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

- $F_1 = F_{\text{SM}} \sim (V_{tq} V_{tb}^*)^2$
- $F_{i \neq 1} = 0$

next-to-MFV

- $|F_i| \sim F_{\text{SM}}$
- arbitrary
phases

generic

- $|F_i| \sim 1$
- 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 $1 \leftrightarrow 2$ 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

$$\begin{array}{c}
 (\delta_{ij}^q)_{AB} \\
 (\tilde{q}_i)_A \text{---} \text{---} \text{---} \times \text{---} \text{---} \text{---} (\tilde{q}_j)_B
 \end{array}
 \quad
 \begin{array}{l}
 q = \{u, d\}, \quad (A, B) = \{L, R\} \\
 (i, j) = \{1, 2, 3\}
 \end{array}$$

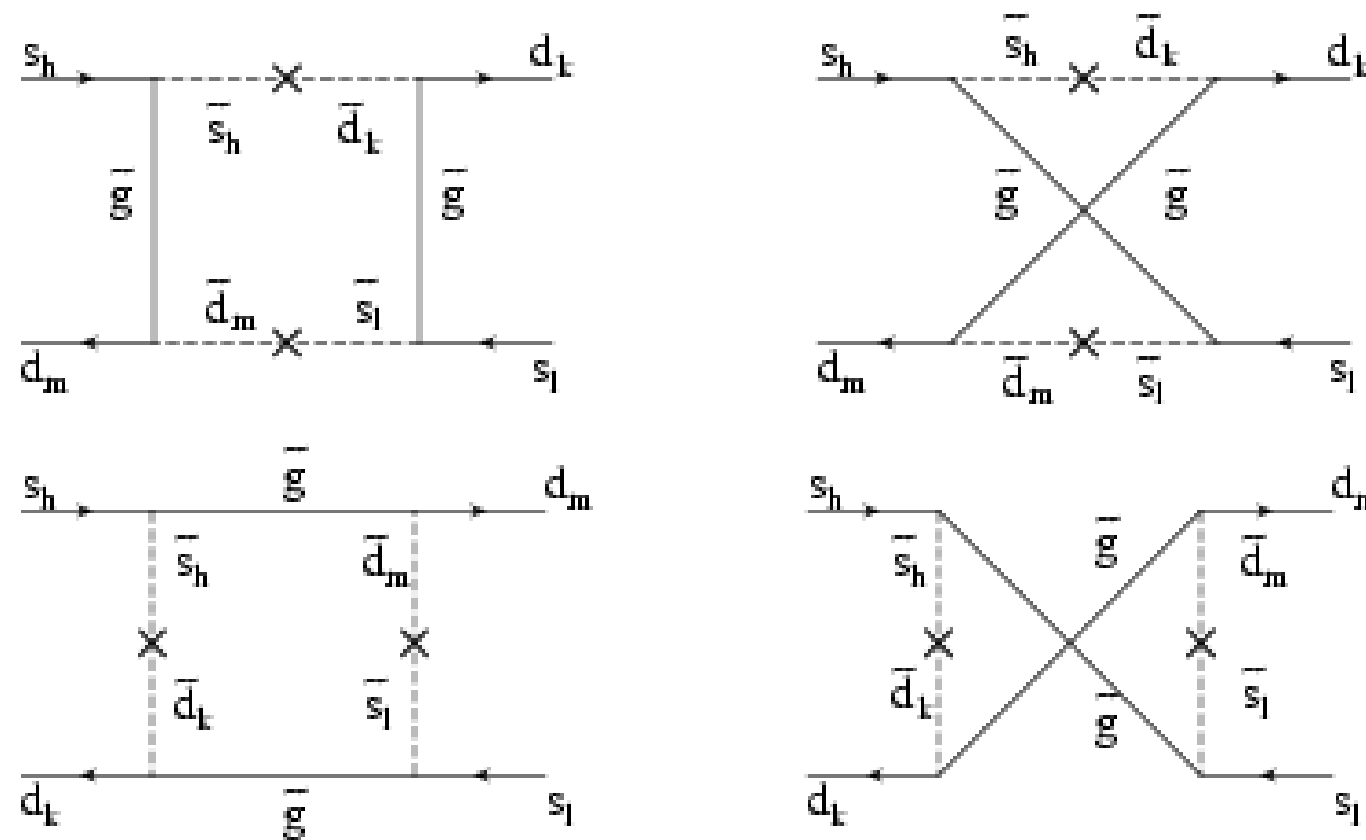
► NP scale: SUSY masses $\tilde{m} \sim m_{\tilde{g}}$

► flavour-violating couplings: $(\delta_{ij}^q)_{AB} \equiv \frac{(M_{ij}^2)^q_{AB}}{\tilde{m}^2}$

$$(M^2)^{\tilde{d}} = \begin{pmatrix} m_{\tilde{d}_L}^2 & m_d(\Lambda_d - \mu \tan \beta) & (\Delta_{12}^d)_{LL} & (\Delta_{12}^d)_{LR} & (\Delta_{13}^d)_{LL} & (\Delta_{13}^d)_{LR} \\ & m_{\tilde{d}_R}^2 & (\Delta_{12}^d)_{RL} & (\Delta_{12}^d)_{RR} & (\Delta_{13}^d)_{RL} & (\Delta_{13}^d)_{RR} \\ & & m_{\tilde{s}_L}^2 & m_s(A_s - \mu \tan \beta) & (\Delta_{23}^d)_{LL} & (\Delta_{23}^d)_{LR} \\ & & & m_{\tilde{s}_R}^2 & (\Delta_{23}^d)_{RL} & (\Delta_{23}^d)_{RR} \\ & & & & m_{\tilde{b}_L}^2 & m_b(A_b - \mu \tan \beta) \\ & & & & & m_{\tilde{b}_R}^2 \end{pmatrix}$$

trivial changes in
the case $\Delta B=2$

**dominant
gluino-squark
contributions
to the Wilson
coefficients**



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

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

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

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

Gabbiani et al.,
hep-ph/9604387

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

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

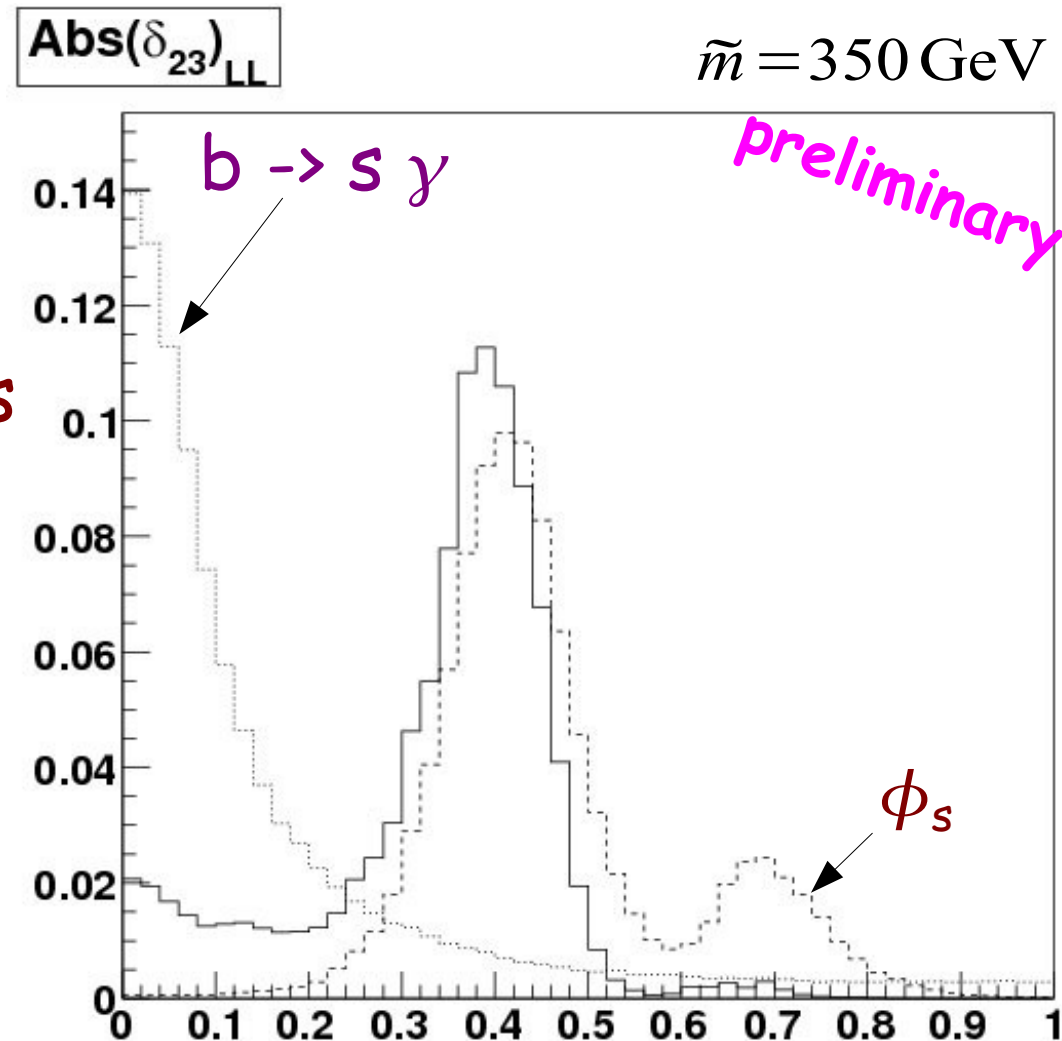
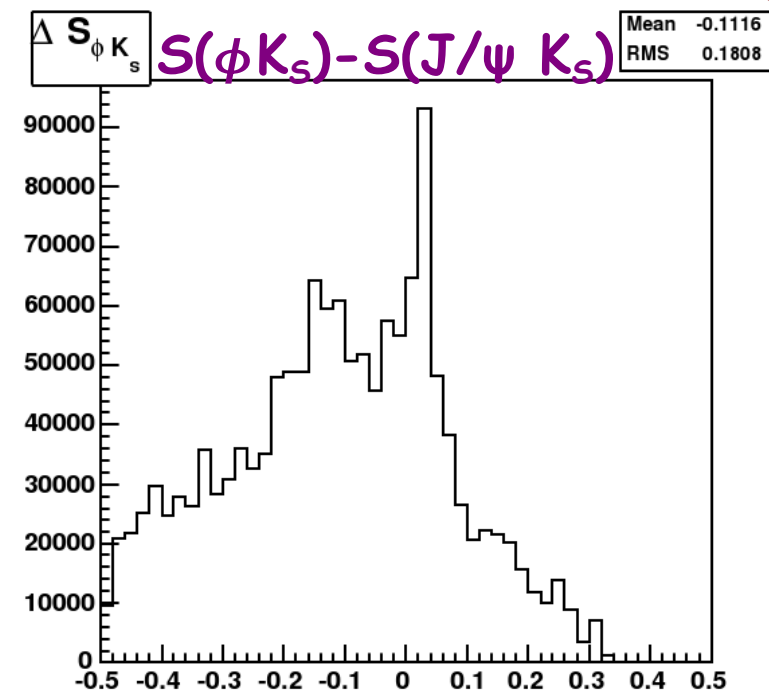
* large MI needed for ϕ_s :

tension with $b \rightarrow s \gamma$

* MI saturates at 1:

upper bound $\tilde{m} < O(1 \text{ TeV})$

* huge effect in $b \rightarrow s$ penguins



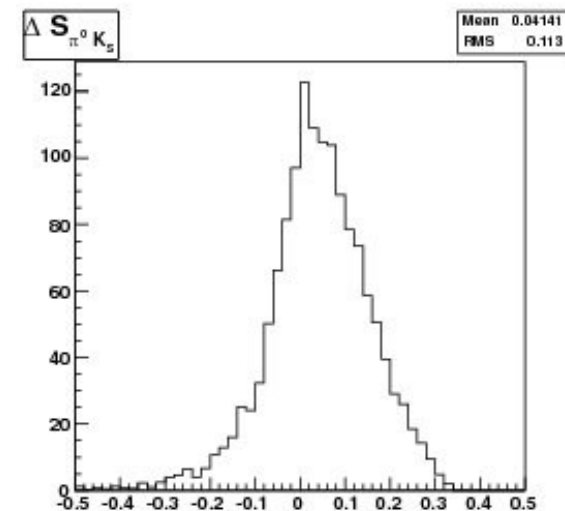
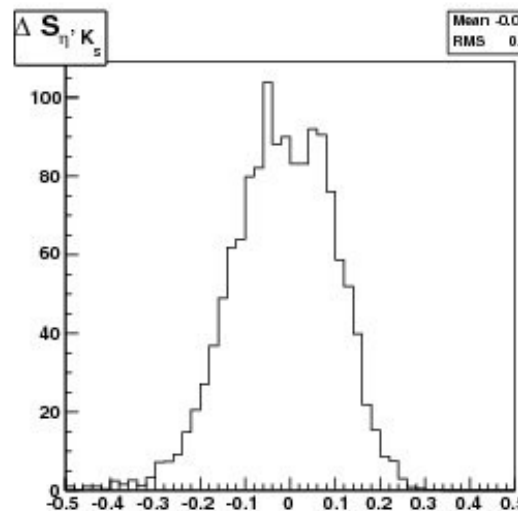
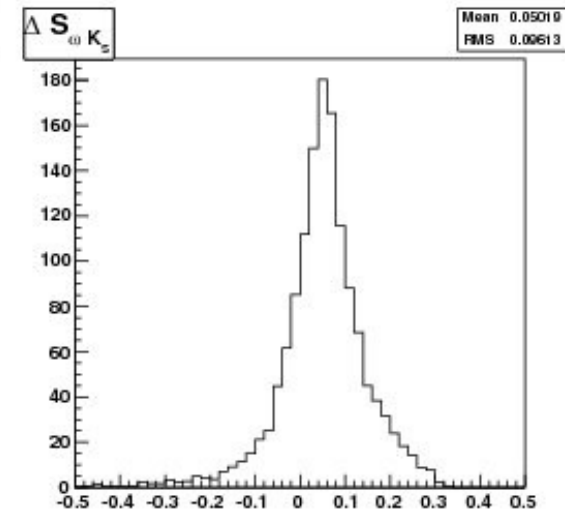
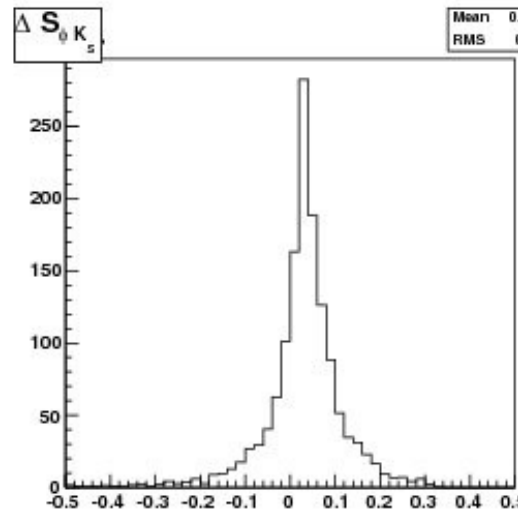
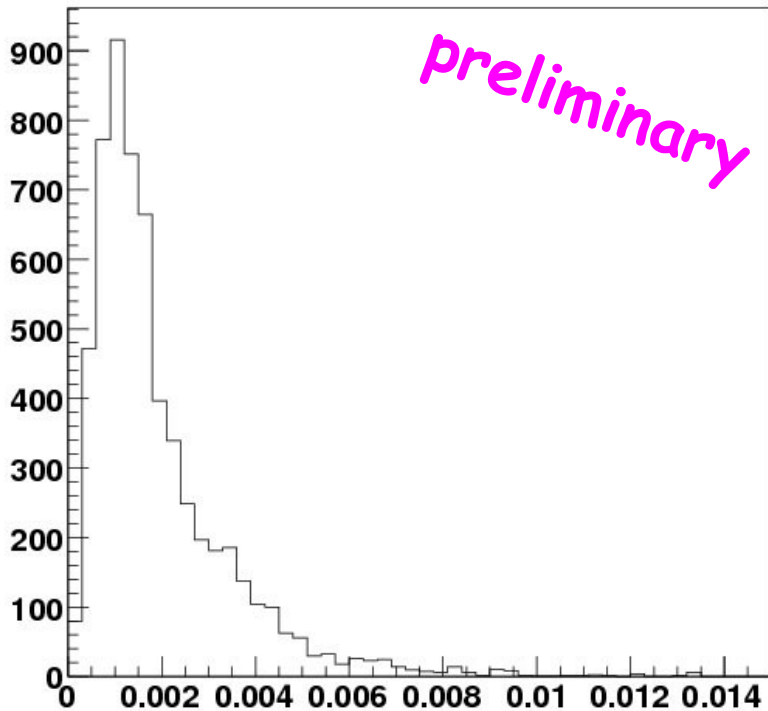
case #2: double mass insertion, $(\delta_{23})_{LL}$ & $(\delta_{23})_{RR}$

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

$b \rightarrow s \gamma$ is no longer a problem

$\text{Abs}(\delta_{23})_{LL} (\delta_{23})_{RR}$

preliminary



* large effects in $b \rightarrow s$ penguins still possible (larger if LR MIs are also switched on)

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

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 :

$$(\delta_{ij}^d)_{RR} \simeq \frac{m_L^2}{m_D^2} (\delta_{ij}^l)_{LL}$$

$$(\delta_{ij}^{u,d})_{LL} \simeq \frac{m_E^2}{m_Q^2} (\delta_{ij}^l)_{RR}$$

$$(\delta_{ij}^u)_{RR} \simeq \frac{m_E^2}{m_U^2} (\delta_{ij}^l)_{LL}$$

$$(\delta_{ij}^d)_{LR} \simeq \frac{m_{L_{ave}}^2}{m_{Q_{ave}}^2} \frac{m_b}{m_\tau} (\delta_{ij}^l)_{RL}^*$$

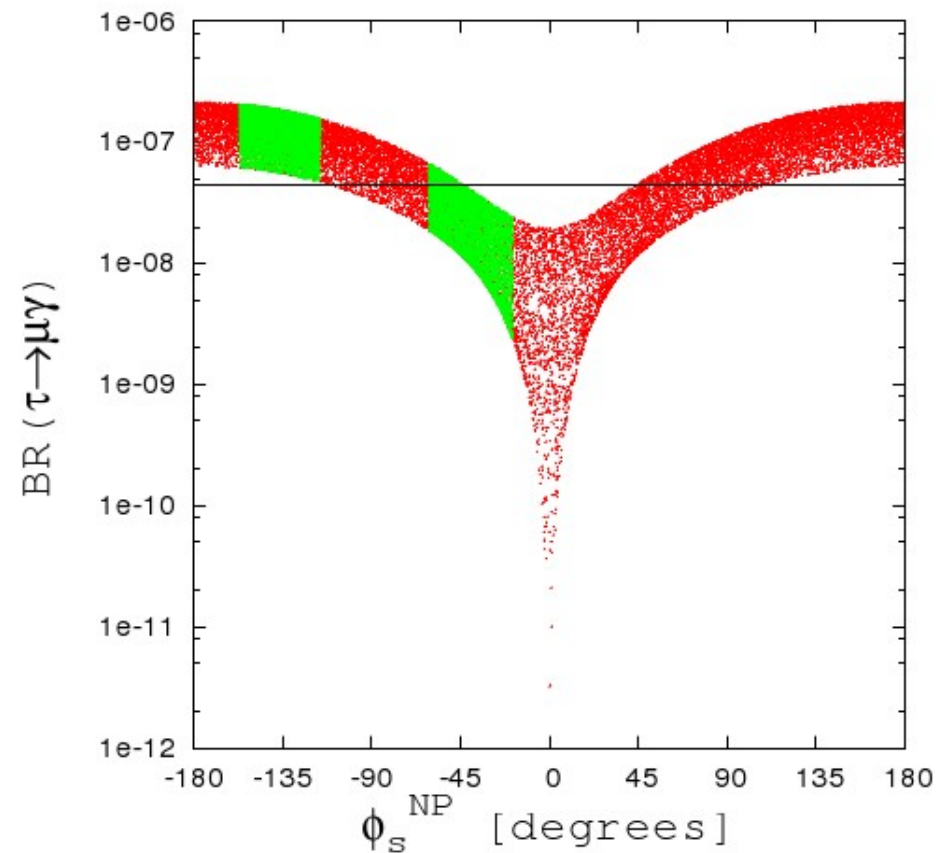
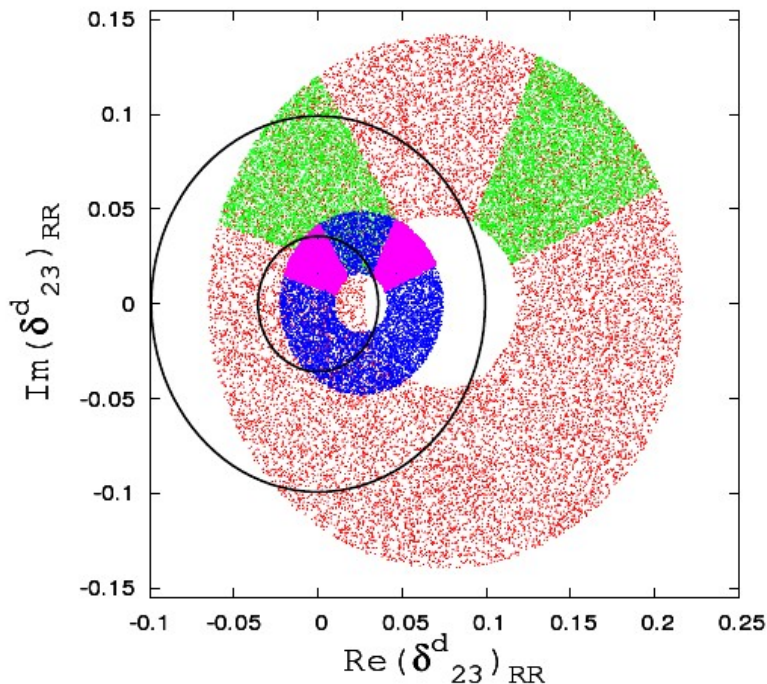
MC et al., hep-ph/0307191

Lower bound on τ FV in SUSY-GUT's

Parry, Zhang, arXiv:0710.5443v2

mass insertion analysis in a
SUSY-GUT scheme

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

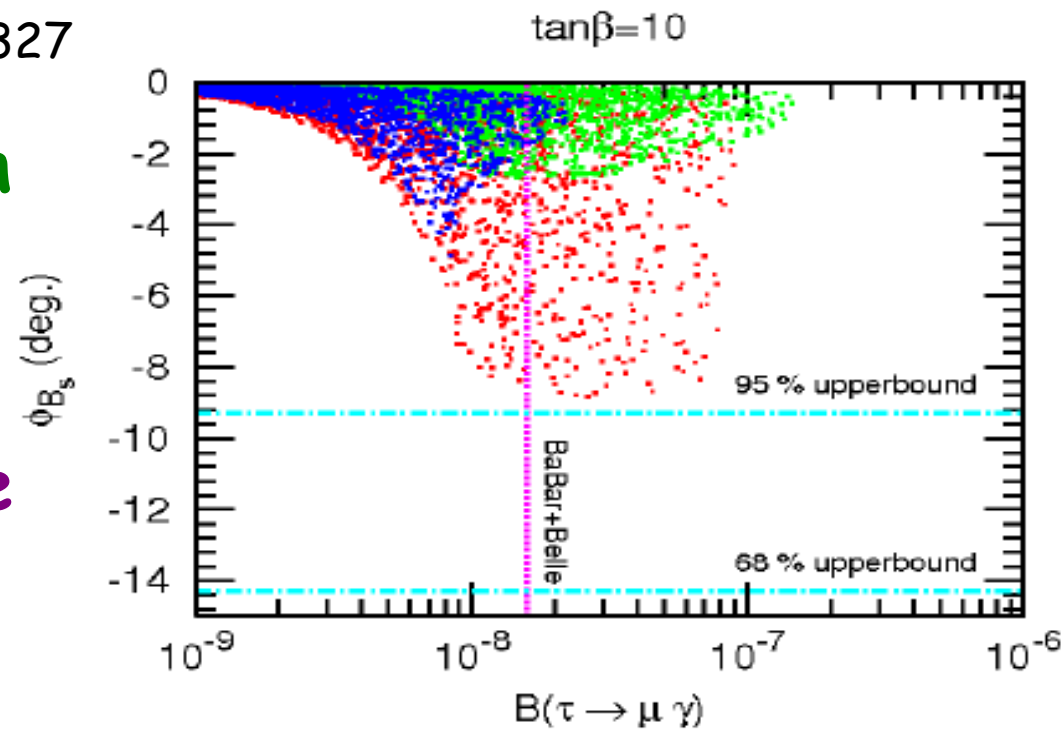


In the UTfit range for the B_s
mixing phase:

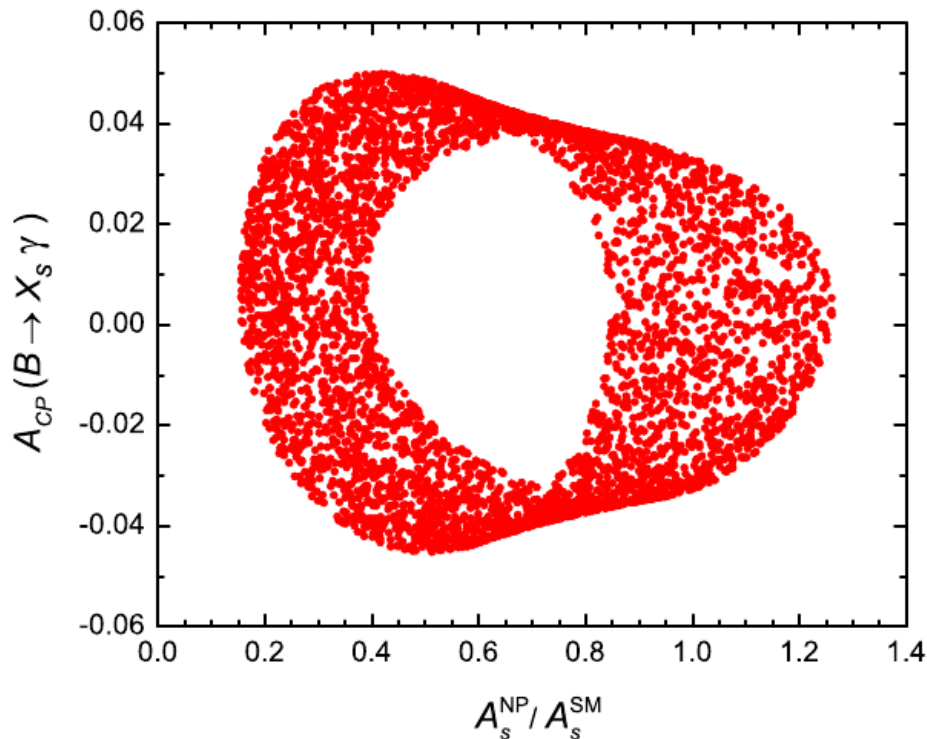
$$\text{BR}(\tau \rightarrow \mu \gamma) > 3 \times 10^{-9} !!$$

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

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



Dutta, Mimura, arXiv:0805.2988



Enlarging the GUT group to $SO(10)$, the correlation φ_s -
BR($\tau \rightarrow \mu \gamma$) can be relaxed
large φ_s correspond
to large CP asymmetries
in $B \rightarrow X_s \gamma$

Spare Slides

Time-dependent angular analysis

TAGGED

UNTAGGED

2-fold ambiguity

4-fold ambiguity

$(\pi-\phi, -\Delta\Gamma_s, \pi-\delta_{1,2})$

$(\pi+\phi, -\Delta\Gamma_s, \pm\delta_{1,2})$

$(-\phi, \Delta\Gamma_s, \pm(\pi-\delta_{1,2}))$

$(\pi-\phi, -\Delta\Gamma_s, \pm(\pi-\delta_{1,2}))$

$$\phi = 2\phi_s$$

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

Dunietz, Fleischer, Nierste
hep-ph/0012219

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

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

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

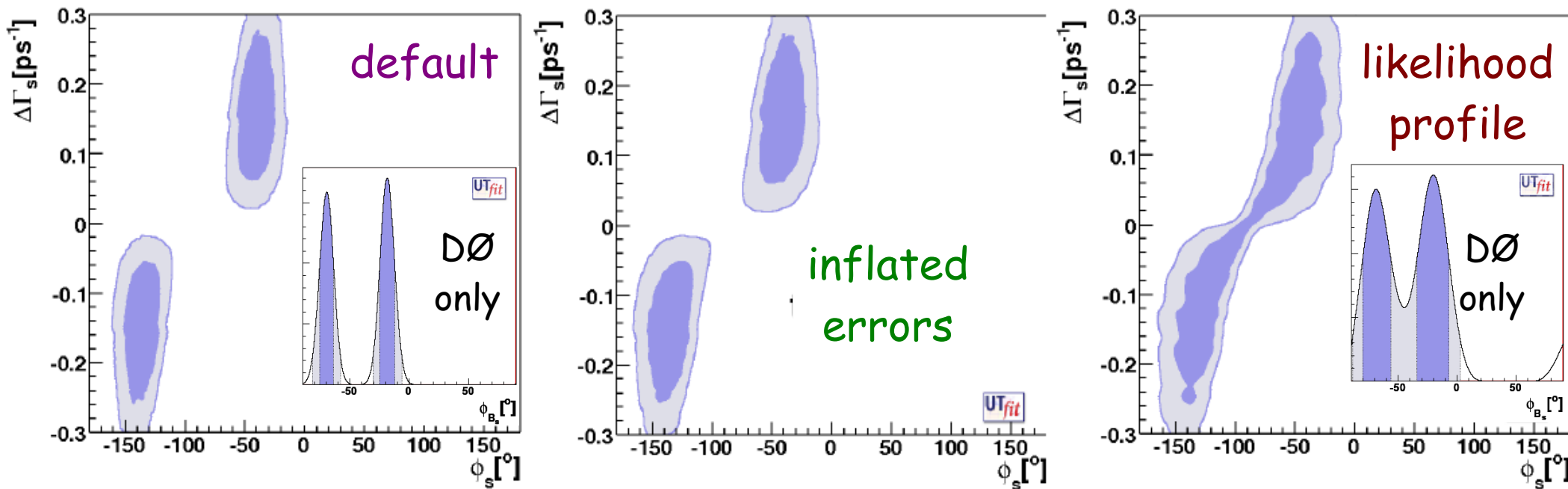
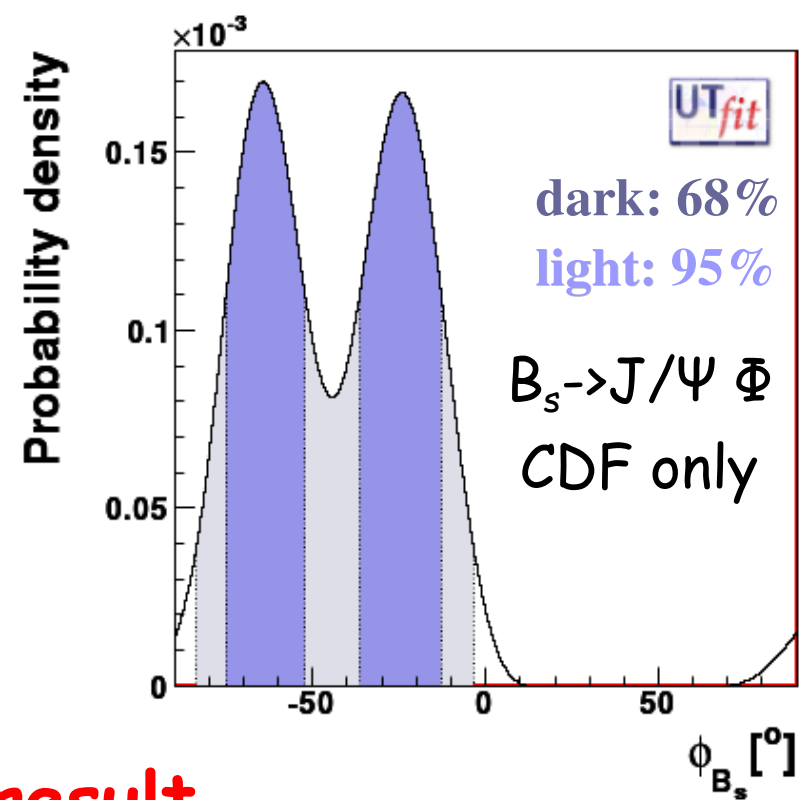
$$\text{Im}\{A_0^*(t)A_{\perp}(t)\} = |A_0(0)||A_{\perp}(0)| e^{-\Gamma t}$$

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

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

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

- * default: CDF likelihood+Gaussian
DØ result with 2x2 corr. matrix
 - * inflated error: as above, but with
error inflated to reproduce the
2 σ 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)

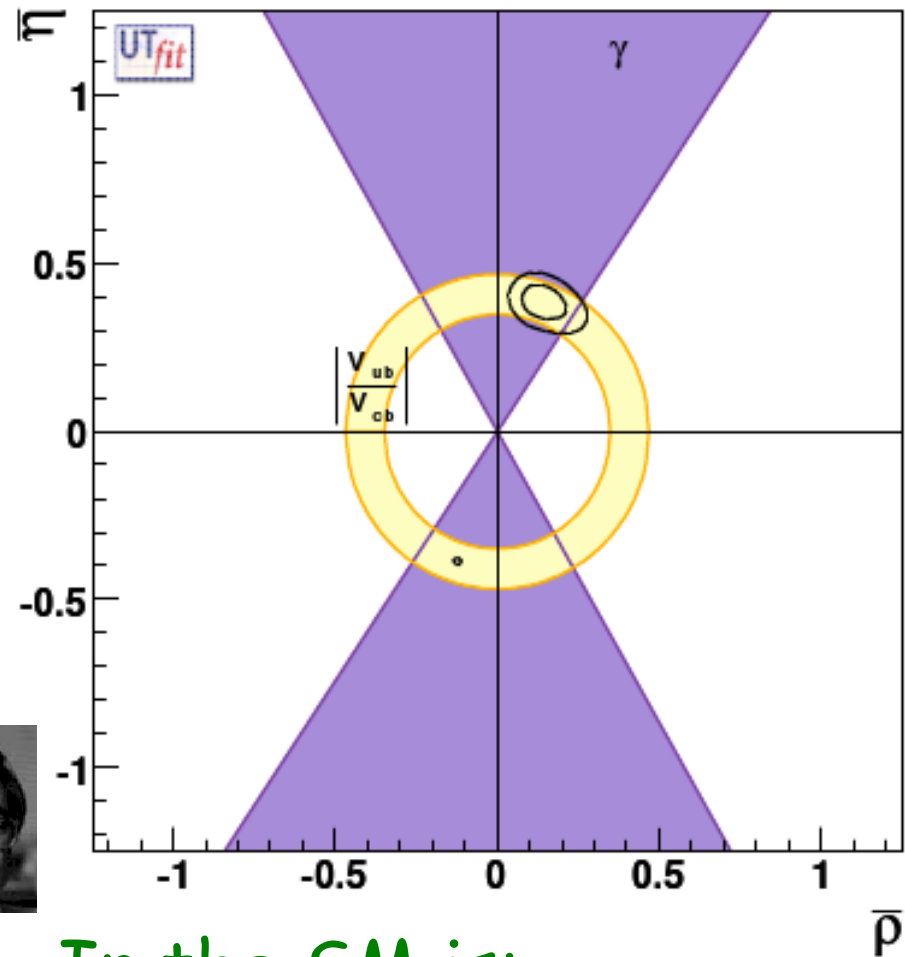
$$V_{CKM} = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \bar{\rho} - i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

$$\lambda = 0.2258 \pm 0.0014$$

$$A = 0.804 \pm 0.001$$

$$\bar{\rho} = 0.140 \pm 0.046$$

$$\bar{\eta} = 0.384 \pm 0.035$$

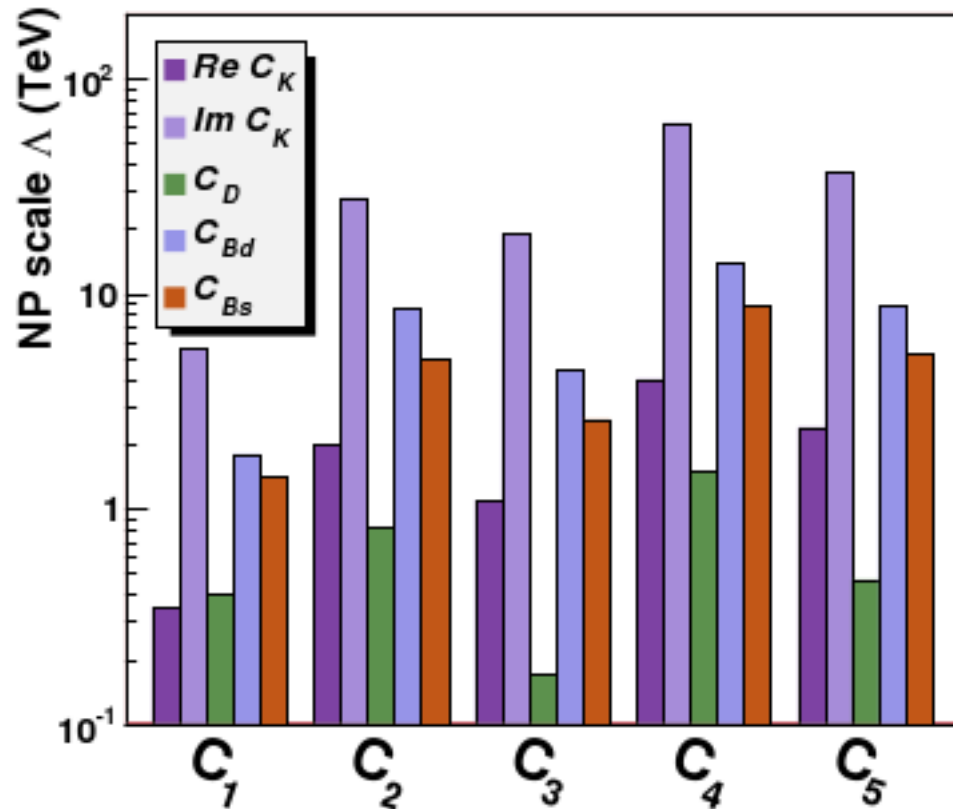


In the SM is:

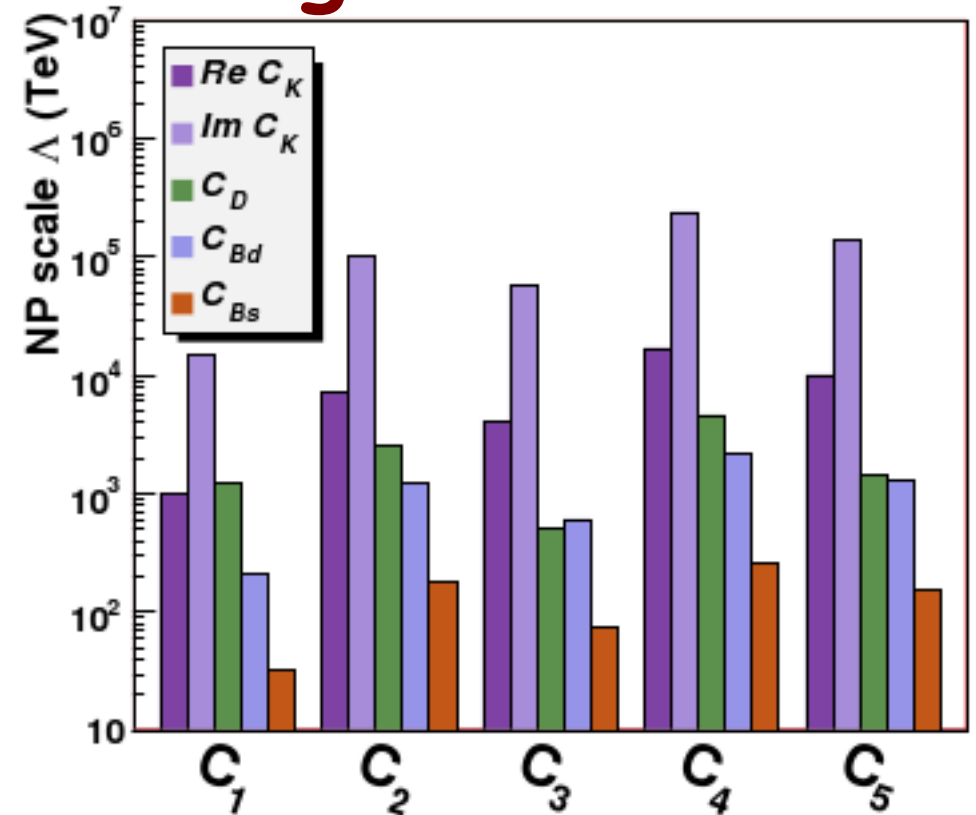
$$\bar{\rho} = 0.147 \pm 0.029$$

$$\bar{\eta} = 0.342 \pm 0.012$$

MFV



generic FV



Contributions of the $\Delta F=2$ operators to the lower bound on the NP scale in the tree/strong interacting case