IMPLICATIONS OF β_s MEASUREMENTS

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- The UTfit analysis of B_s mixing (arXiv:0803.0659, updates)
  - Ingredients
  - Results
- Implications for NP
  - General considerations
  - SUSY: Bounds on $(\delta^d_{23})_{AB}$ and $b \to s$ penguins
- Conclusions

Thanks to M. Rescigno, M. Ciuchini, M. Pierini

INTRODUCTION

The SM contribution to CP violation in B_s mixing is very well predicted and small:

- Sin $2\beta_s$ = 0.037 ± 0.002 (SM or MFV)
- Sin $2\beta_s$ = 0.041 ± 0.004 (Arbitrary NP)

Thus, observing a mixing phase significantly different from 0.041 ± 0.004 would be a very clean signal of NP in B_s mixing.

General parametrization of NP in B_s mixing

Mixing amplitude = SM contribution + NP contribution

$$C_{B_s}\, e^{2i\phi_{B_s}} = \frac{A_s^{\rm SM} e^{-2i\beta_s} + A_s^{\rm NP} e^{2i(\phi_s^{\rm NP}-\beta_s)}}{A_s^{\rm SM} e^{-2i\beta_s}} = \frac{\langle B_s | H_{\rm eff}^{\rm full} | \bar{B}_s \rangle}{\langle B_s | H_{\rm eff}^{\rm SM} | \bar{B}_s \rangle}$$

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

C_{pen} and ϕ_{pen} parameterize possible NP contributions to $\Gamma^q{}_{12}$ from $b \to s$ penguins (a small effect, entering only at NLO)

OBSERVABLES WE USE - THEORY

$$\Delta m_s = |A_s^{\text{full}}| = C_{B_s} (\Delta m_s)^{\text{SM}}$$

$$2\phi_s = -\arg A_s^{\text{full}} = 2(\beta_s - \phi_{B_s})$$

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

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

$$\frac{\Delta\Gamma_s}{\Delta m_s} = \text{Re}\left(\frac{\Gamma_{12}^s}{A_s^{\text{full}}}\right)$$

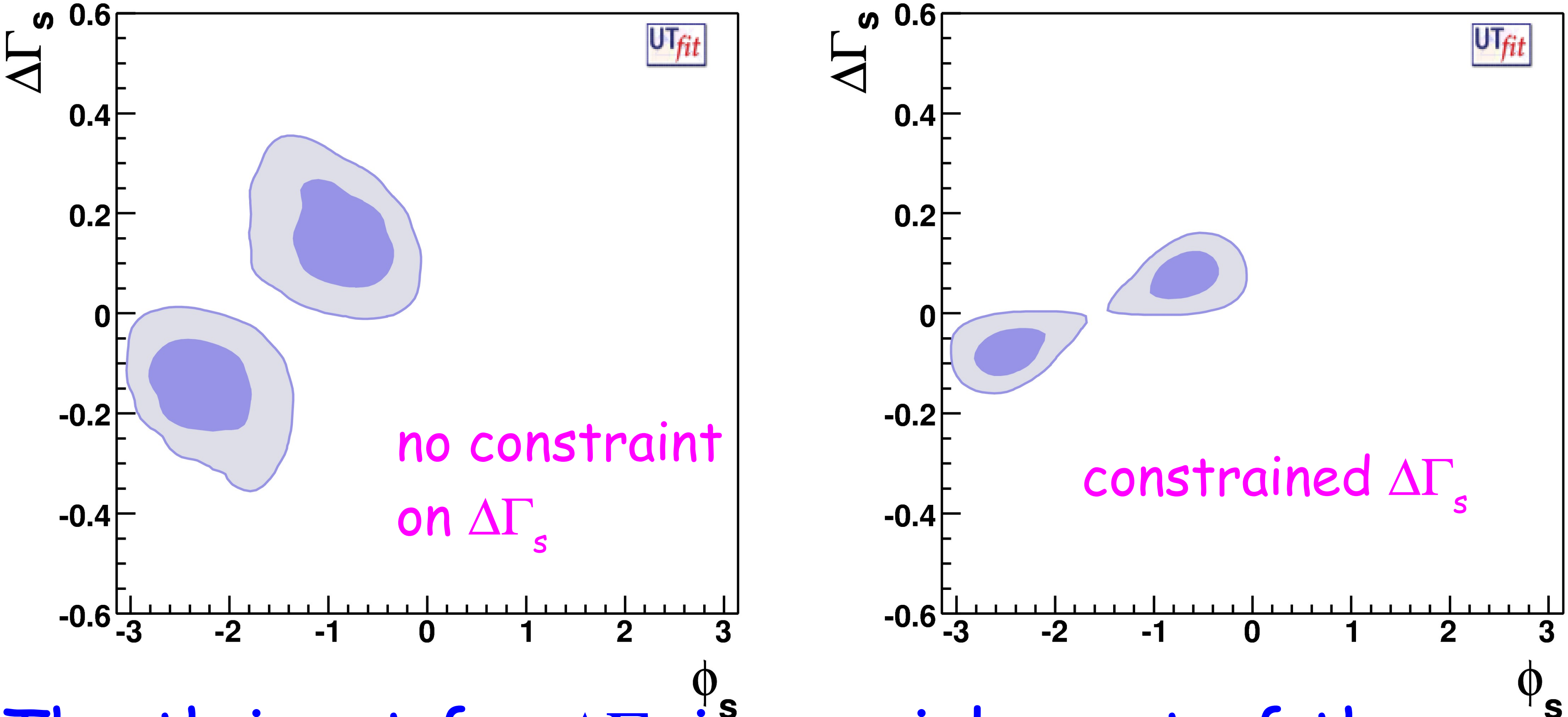
$$\tau_{B_s}^{FS} = \frac{1}{\Gamma_s} \frac{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$

OBSERVABLES WE USE - EXPT

Δm_s [ps^{-1}]	17.77 ± 0.12	
$A^s_{\rm SL} \times 10^2$	-0.20 ± 1.19	New!
$A^{\mu\mu}_{\rm SL} \times 10^3$	-4.3 ± 3.0	
$\tau^{\rm FS}_{B_s}$ [ps]	1.461 ± 0.032	

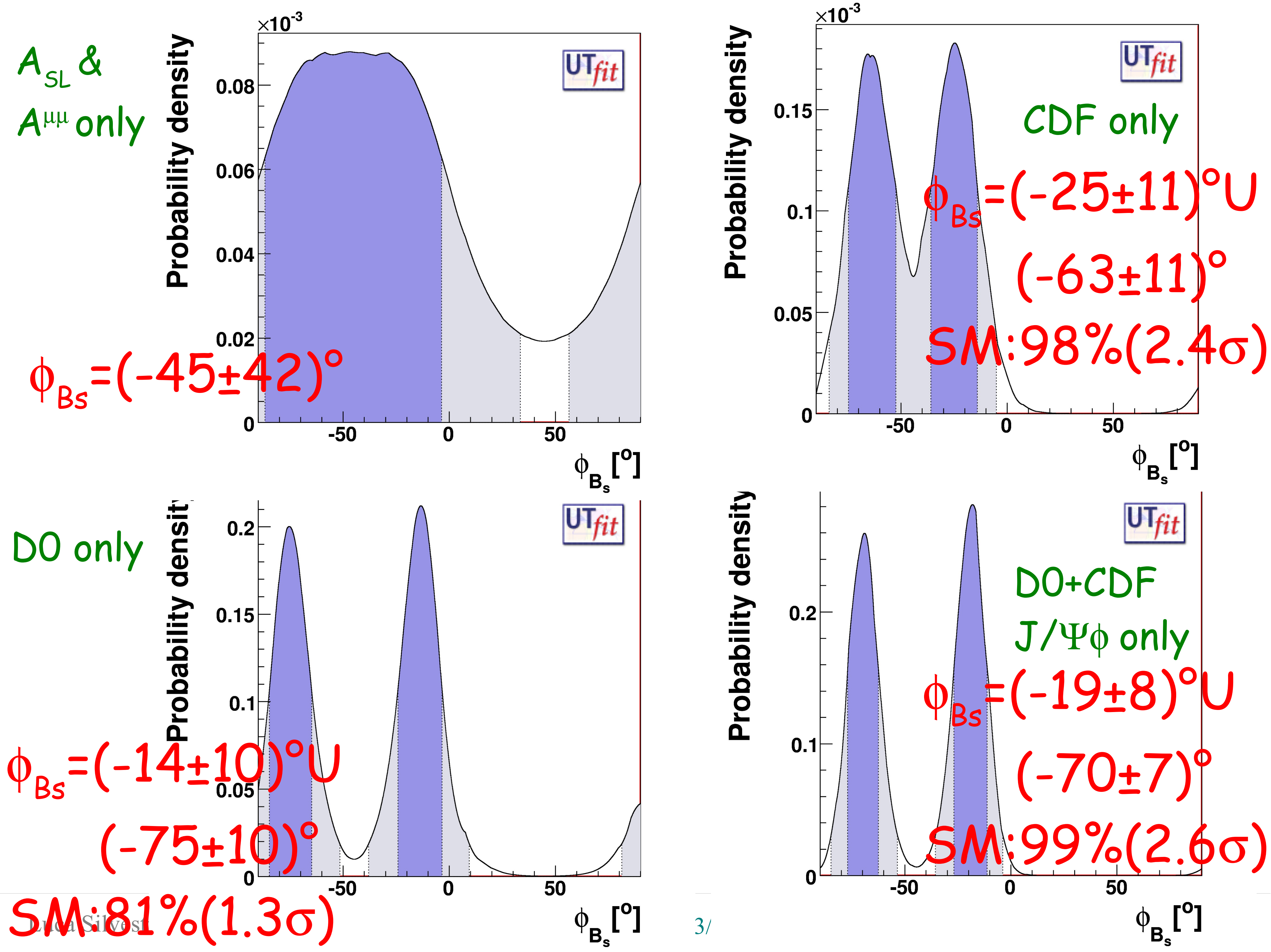
Tagged analysis of $B_s \to J/\Psi\phi$ from CDF and D0: use 2D likelihood for $\Delta\Gamma_s$ vs ϕ_s New!

Unfortunately, new CDF likelihood not yet available: use published measurement



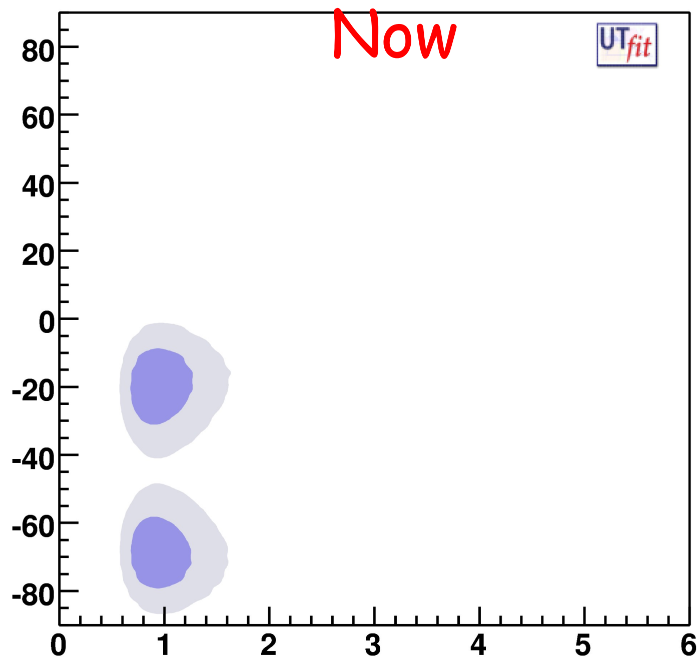
The th input for $\Delta\Gamma_s$ is crucial: most of the exp allowed region has a too large $|\Delta\Gamma_s|$.

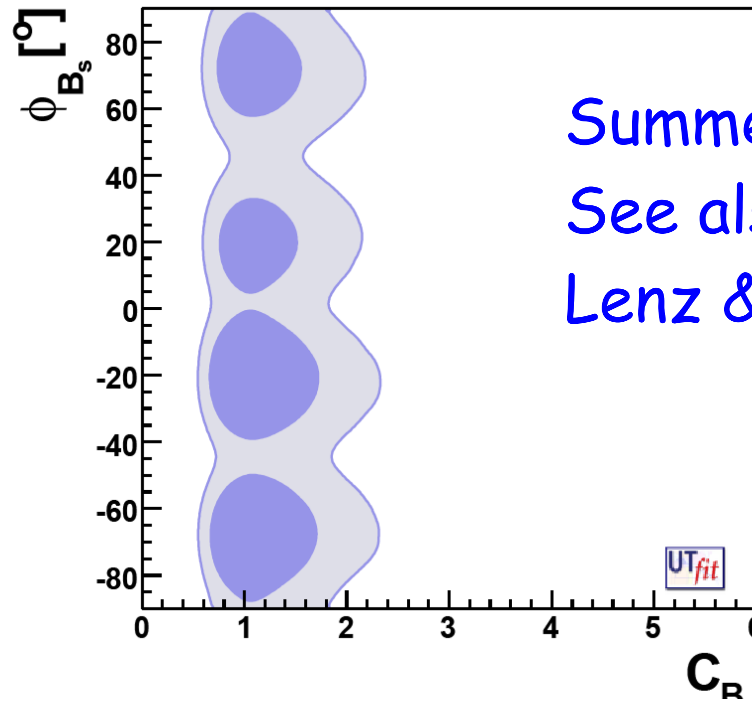
We use a conservative estimate of the SM error and allow NP to enter $\Delta\Gamma_s$ through NP penguins.



A_{SL} &
$A^{\mu\mu}$ only
ϕ_{Bs}=(-45±42)°
Probability density
×10^-3
0.08
0.06
0.04
0.02
0
-50
0
50
ϕ_{B_s} [°]
UTfit
CDF only
ϕ_{Bs}=(-25±11)°U
(-63±11)°
SM:98%(2.4σ)
0.15
0.1
0.05
D0 only
ϕ_{Bs}=(-14±10)°U
(-75±10)°
SM:81%(1.3σ)
0.2
D0+CDF
J/Ψφ only
ϕ_{Bs}=(-19±8)°U
(-70±7)°
SM:99%(2.6σ)

Now



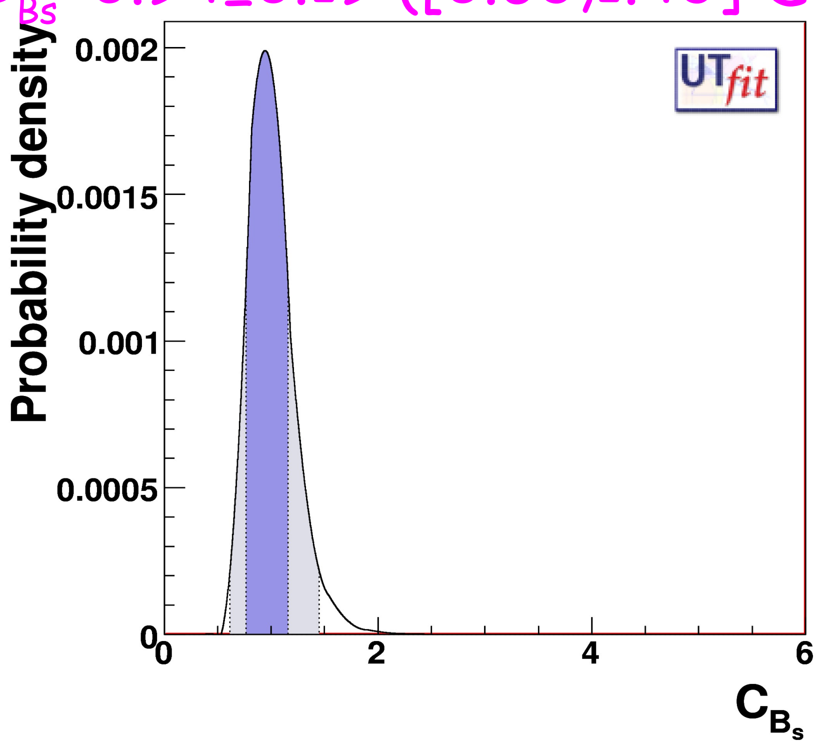


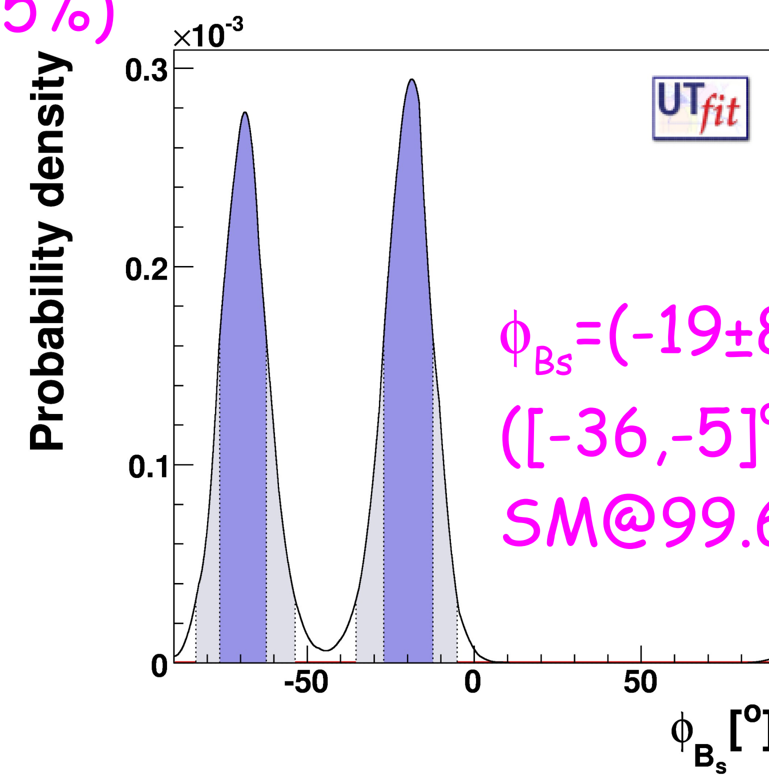
Summer 07

See also

Lenz & Nierste 07

C_{Bs}=0.94±0.19 ([0.63,1.43] @ 95%)

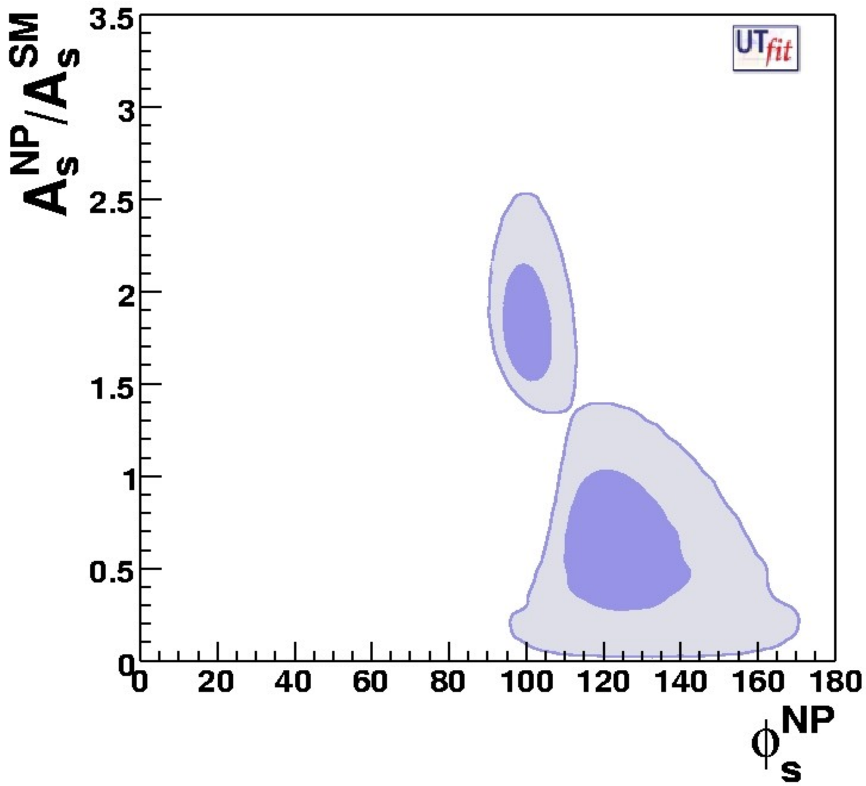




$\phi_{Bs}=(-19\pm8)^\circ \cup (-69\pm7)^\circ$

$([-36,-5]^\circ \cup [-83,-54]^\circ)$

SM@99.6% (2.9σ)

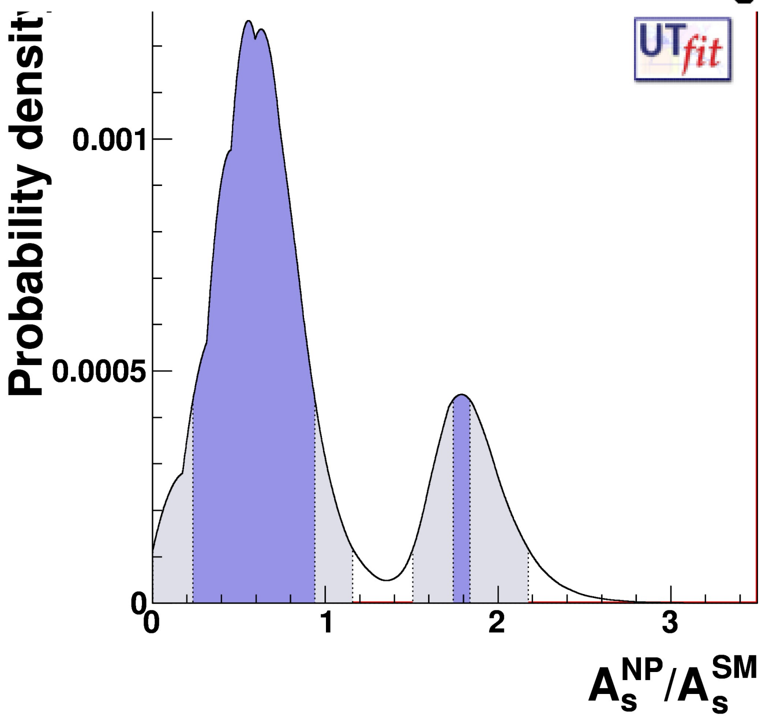


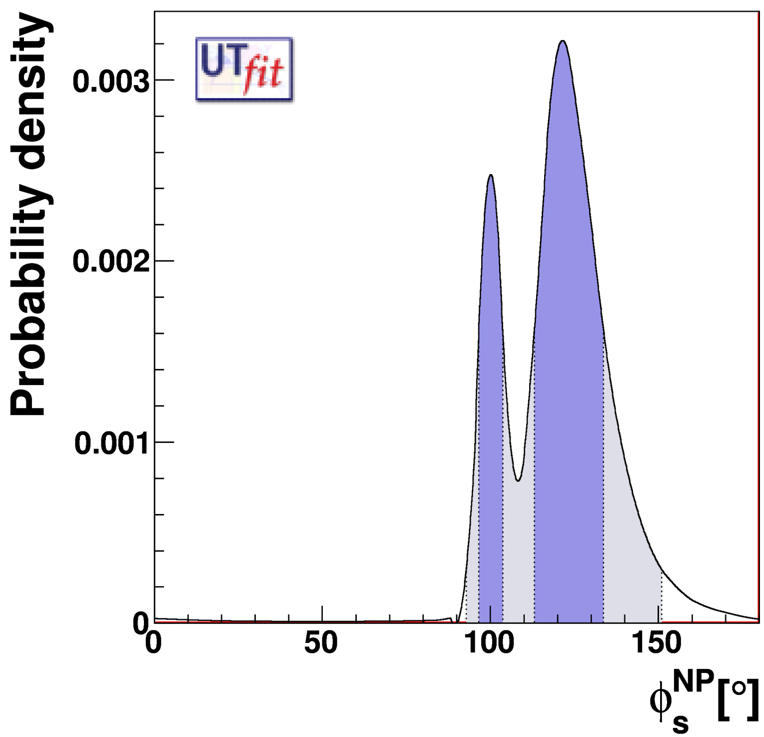
The two solutions for ϕ_s correspond to two regions for A_s^{NP} and ϕ_s^{NP}:

$A_s^{NP}/A_s^{SM}=0.6\pm0.4$ & $\phi_{NP}=-57\pm10$

$A_s^{NP}/A_s^{SM}=1.8\pm0.1$ & $\phi_{NP}=-80\pm3$

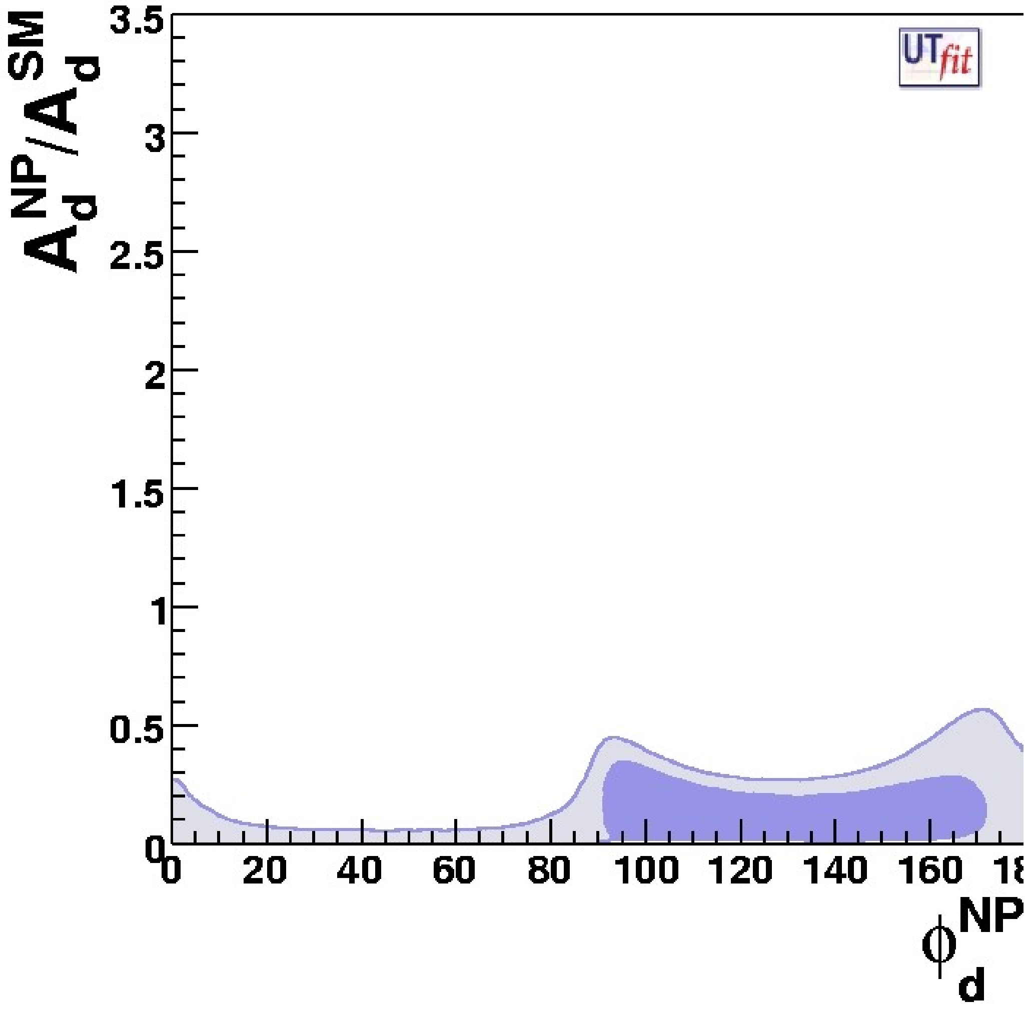
Requires NP with new sources of CP violation!

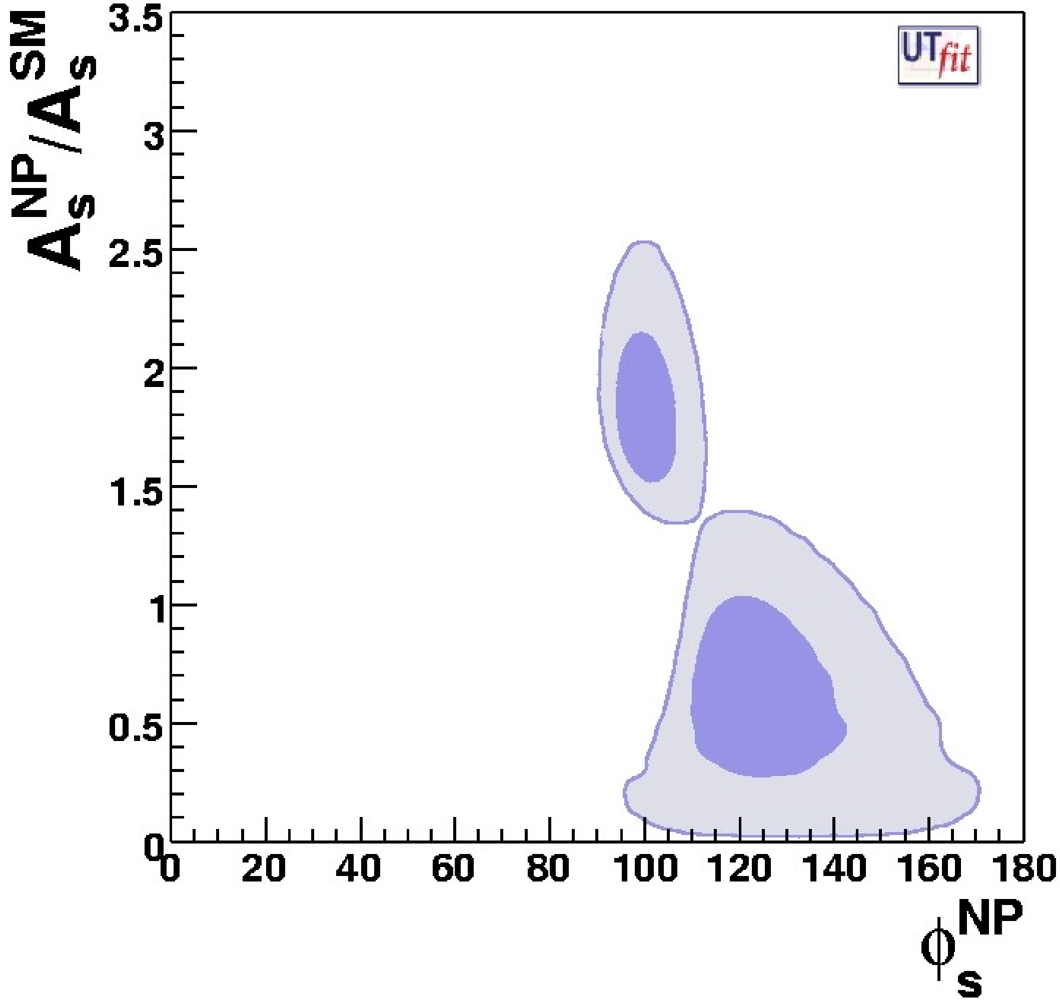




IMPLICATIONS ON NP

- We find nonstandard CP violation in B_s mixing at $\sim 3\sigma \Rightarrow$ evidence of NP!
- Need NP at the level of ~60% with a maximal phase in B_s mixing
- Nonstandard CPV in B_d and K can be ~ 10%
- Need a flavour structure, but not NMFV!





$A^{NP}{}_d/A^{SM}{}_d$~0.1 and $A^{NP}{}_s/A^{SM}{}_s$~0.6 correspond to $A^{NP}{}_d/A^{NP}{}_s \sim \lambda$ i.e. to an additional λ wrt NMFV

IMPLICATIONS ON NP - II

- 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.; …

IMPLICATIONS ON NP - III

- In a given model expect correlation between b $\leftrightarrow$ s (B_s mixing) and b $\rightarrow$ s (penguin decays) transitions
- This correlation is welcome given the large room for NP in b $\rightarrow$ 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

THE MSSM

- In the MSSM, two classes of contributions to FCNC's:
  - Supersymmetrization of SM contributions ($W \to \tilde{w}$, $t \to \tilde{t}$) + $H^{\pm}$: dominant in MFV
  - pure SUSY contributions: $\tilde{g}$ - $\tilde{q}$: requires new sources of flavour violation in squark mass matrices

Hall, Kostelecky & Raby; Gabbiani et al.

THE GENERAL MSSM

Ciuchini et al., in progress, Preliminary

- We consider a MSSM with generic soft SUSY-breaking terms, but
  - dominant gluino contributions only
  - mass insertion approximation

Think of δ's as SUSY equivalent of CKM mixing

$$\tilde{d}^i_A \cdots\cdots \times_{\left(\delta^d_{ij}\right)_{AB}} \cdots\cdots \tilde{d}^j_B$$

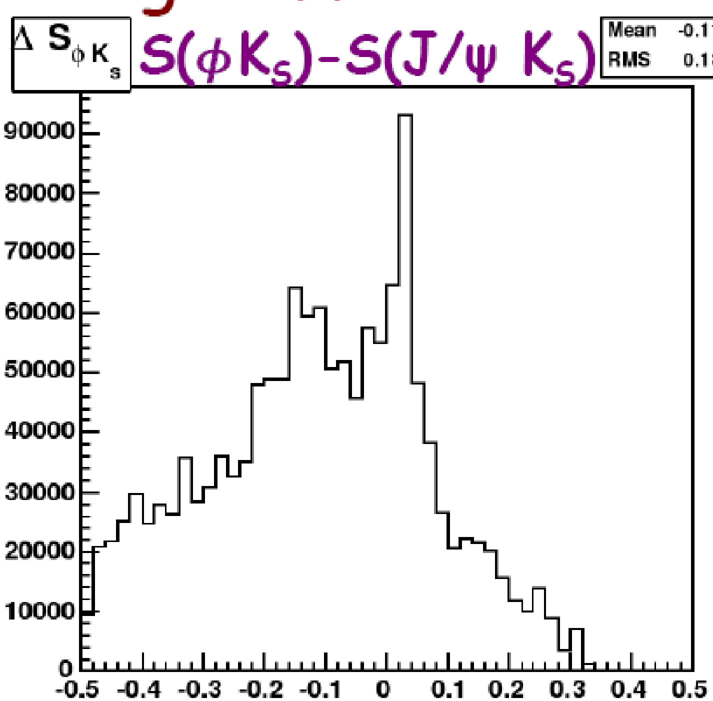
four insertions AB=LL, LR, RL, RR

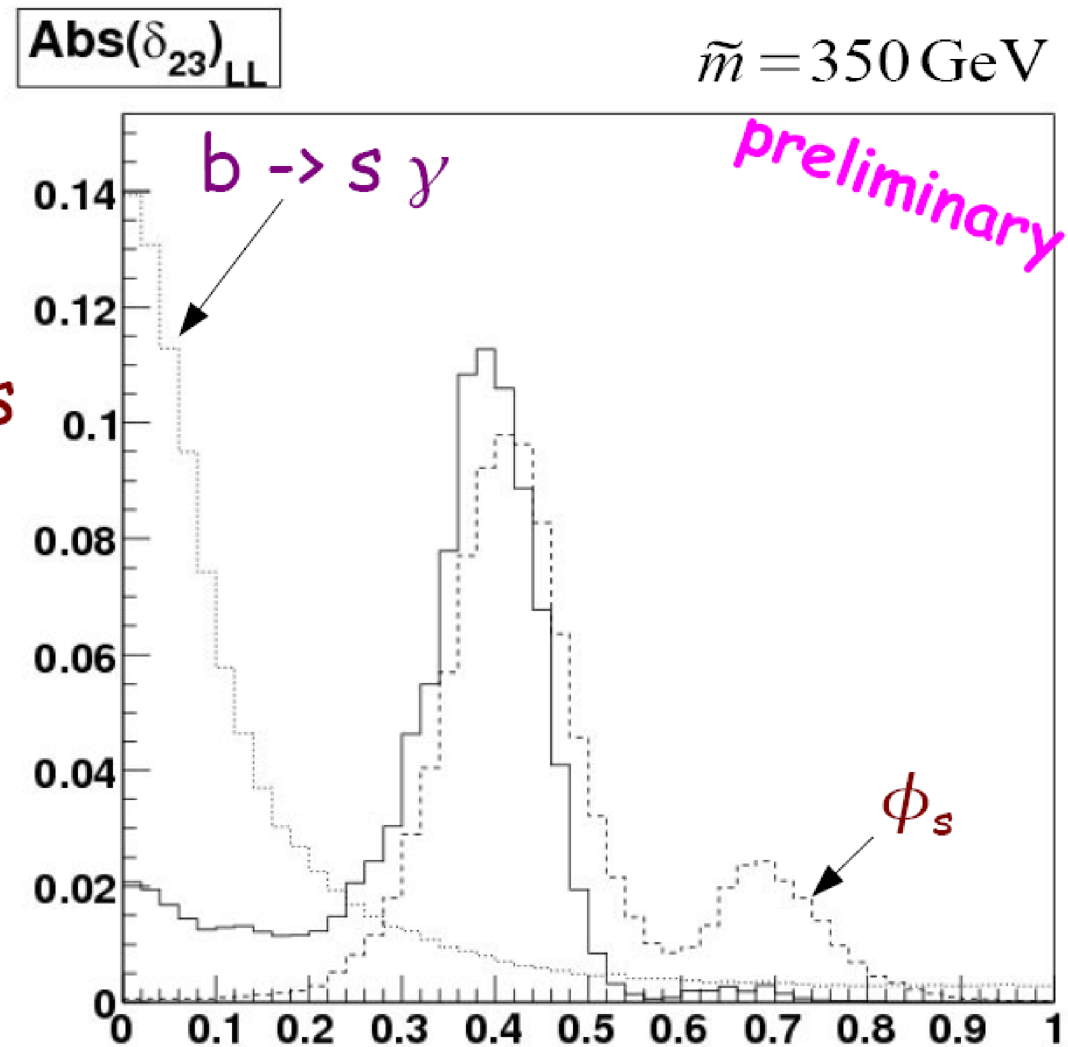
take m_{SUSY}=350 GeV for reference

* chirality-flipping mass insertions are strongly bounded by b -> s γ: they are too small to produce the measured ϕ_s

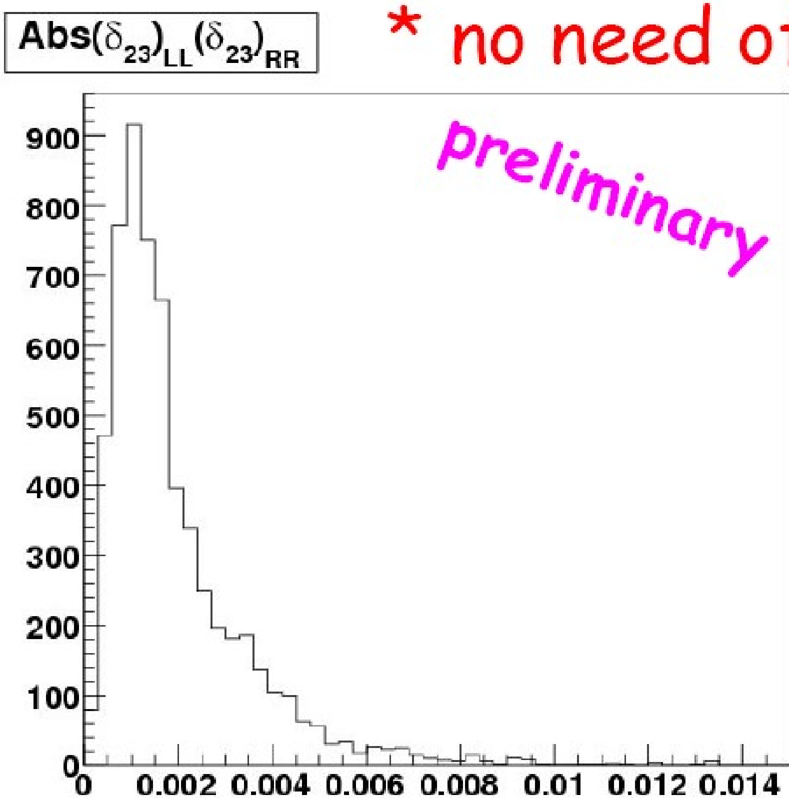
<u>case #1</u>: single mass insertion, e.g. $(\delta_{23})_{LL}$

* large MI needed for ϕ_s: tension with b -> s γ
* MI saturates at 1: upper bound $\tilde{m}$ < O(1 TeV)
* huge effect in b->s penguins



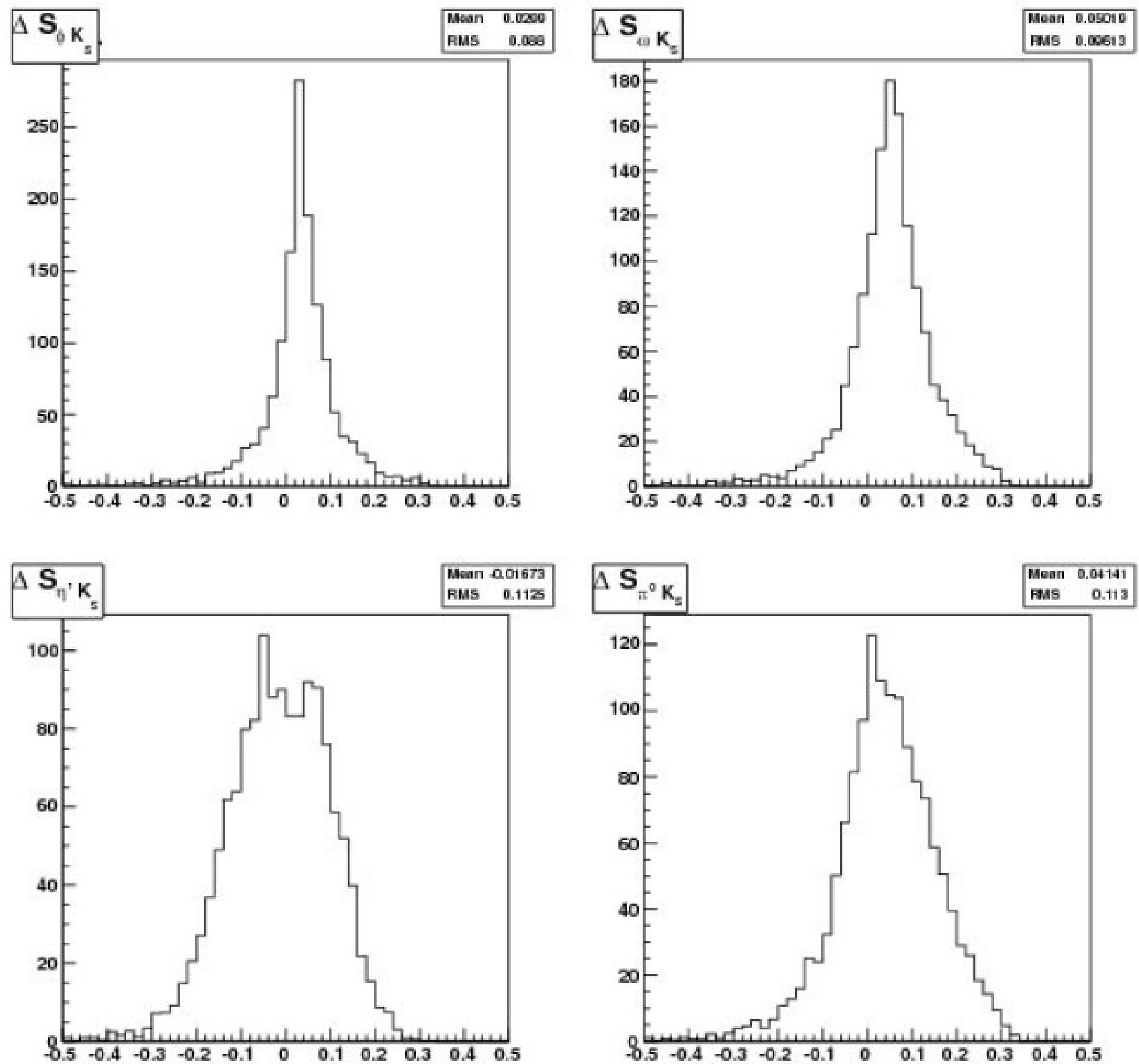


case #2: double mass insertion, $(\delta_{23})_{LL}$ & $(\delta_{23})_{RR}$



* 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)

$b\to s$ and $\tau\to\mu$ in SUSY-GUTs

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

Ciuchini et al, hep-ph/0307191

The following relations hold at M_Z:

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

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

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

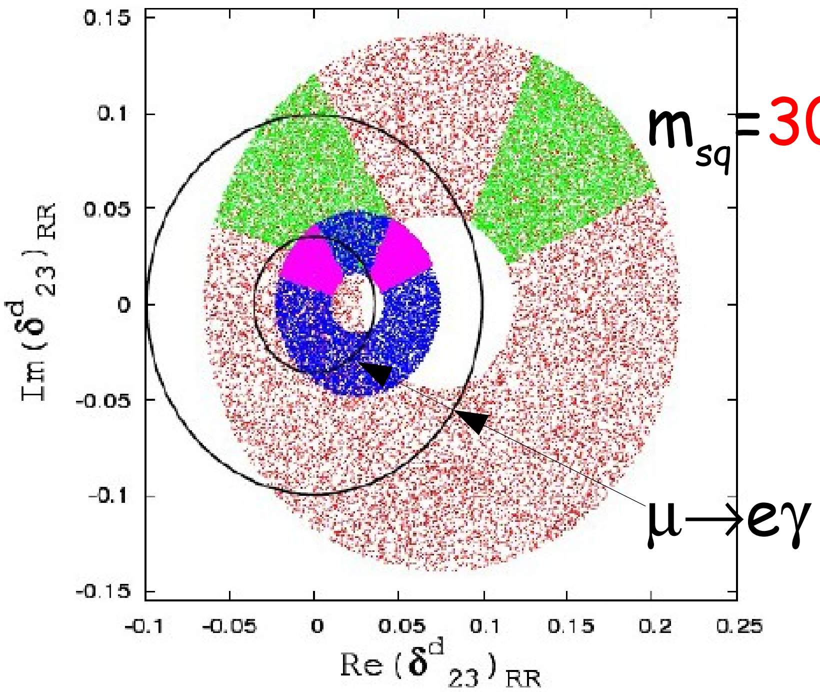
$$(\delta^d_{ij})_{LR} \simeq \frac{m^2_{L_{ave}}}{m^2_{Q_{ave}}}\frac{m_b}{m_\tau}(\delta^l_{ij})^*_{RL}$$

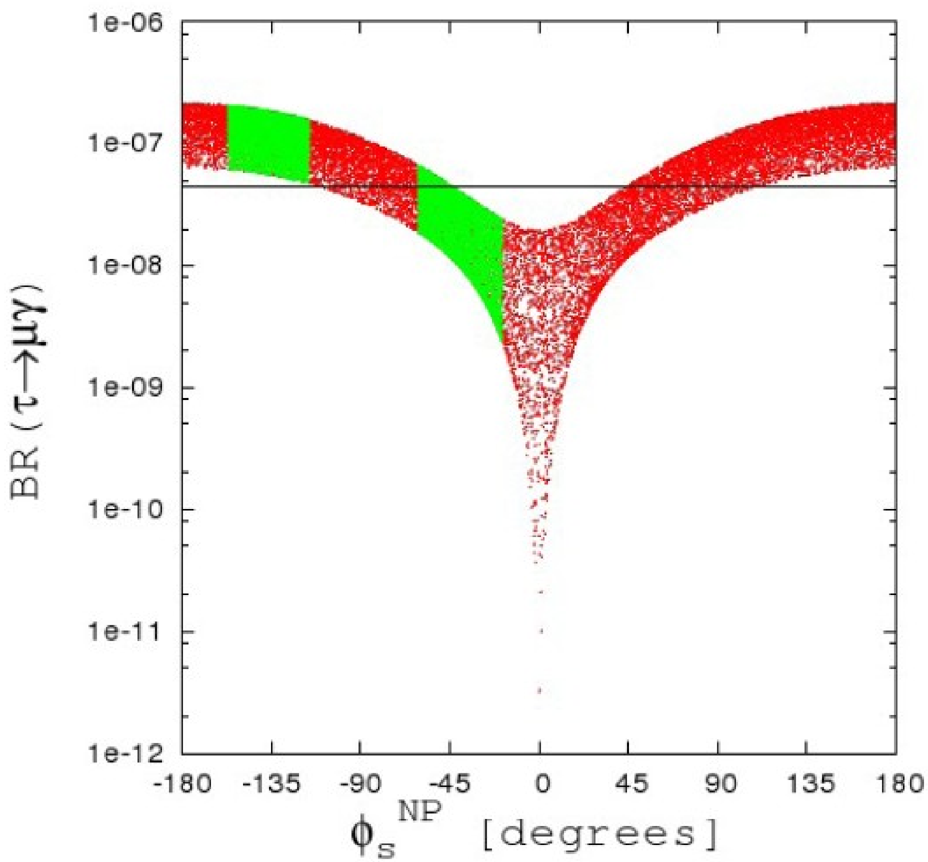
A LOWER BOUND ON $\tau\to\mu\gamma$

Parry, Zhang, arXiv:0710.5443v2

mass insertion analysis in a SUSY-GUT scheme

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





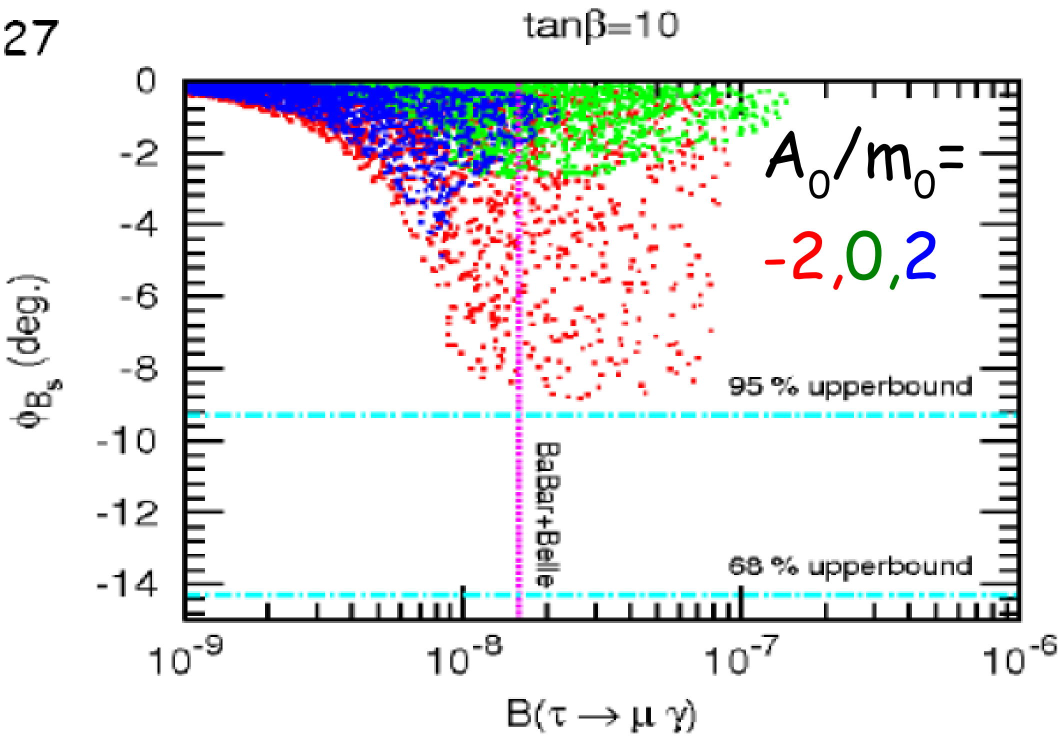
In the UTfit range for the B_s mixing phase:

$$BR(\tau\to\mu\gamma) > 3\times10^{-9}\ !!$$

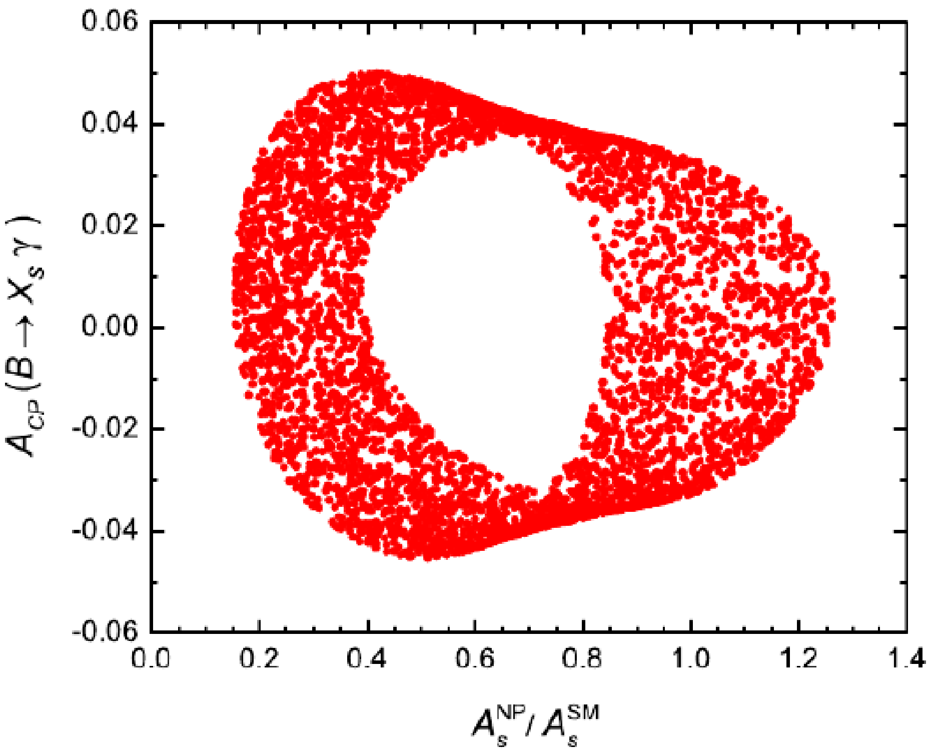
Hisano, Shimizu, arXiv:0805.3327

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 $B \to X_s\gamma$

CONCLUSIONS

- We have evidence of nonstandard CP violation in B_s mixing, pointing to non-MFV extensions of the SM
- Nonstandard CPV is small in B_d and K mixing, pointing to a specific NP structure
- Correlation with $b \to s$ penguins and/or $\tau \to \mu\gamma$ is possible
- If confirmed, expect NP in the LHC range and more NP effects at LHCb/SuperB!