B PHYSICS: THEORY AND B-FACTORY RESULTS

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- Introduction
- New physics in B_q mixing
- New physics in B_q penguin decays
- Minimal flavour violation @ large $\tan\beta$
- Conclusions and outlook

INTRODUCTION

The Standard Model works beautifully up to a few hundred GeV's, but it must be an effective theory valid up to a scale $\Lambda \leq M_{planck}$:

$$\mathcal{L}(M_W) = \Lambda^2 H^\dagger H + \lambda \left(H^\dagger H\right)^2 + \mathcal{L}_{\rm SM}^{\rm gauge} + \mathcal{L}_{\rm SM}^{\rm Yukawa} + \frac{1}{\Lambda}\mathcal{L}^5 + \frac{1}{\Lambda^2}\mathcal{L}^6 + \ldots$$

EW scale

Has accidental symmetries

Violates accidental symmetries

Two accidental symmetries of the SM are crucial for our discussion:

1) Absence of tree-level flavour changing neutral currents, GIM suppression of FCNC @ the loop level

2) No CP violation @ tree level

$\Rightarrow$ Flavour physics extremely sensitive to NP!!

- SM flavour symmetry strongly broken by the top Yukawa coupling

  $\Rightarrow$ no symmetry expected to protect NP contributions to B physics

- Any NP that stabilizes the EW scale must cancel top contribution to Higgs mass

  $\Rightarrow$ "top-like" NP cannot decouple

  $\Rightarrow$ expect sizable effects in B physics

- Bottom Yukawa coupling is O(1) in 2HDM @ large tanβ $\Rightarrow$ large effects in B physics

LOOKING FOR NP IN B DECAYS

Consider most NP sensitive processes:

- $\Delta F=2$: B_q mixing & CPV
- $\Delta F=1$: penguin transitions $b \to s,d V$ ($V = Z, g^*, \gamma^{(*)}$) ex. $B \to K\pi$, $B \to K^* l^+ l^-$
- chirally suppressed: $B \to \tau\nu$, $B_q \to \mu^+\mu^-$, $B \to X_{s,d}\,\gamma$

New Physics in B_q-$\bar{B}_q$ mixing

B_q mixing is governed by:

- M_{12}, dominated by the exchange of virtual heavy states (top + NP) in loops
- Γ_{12}, dominated by real intermediate states $\Rightarrow$ tree-level dominated

Assume that NP is a negligible correction to tree level processes (not for chirally suppressed ones)

$M^{full}_{12} = \langle B|H^{eff}|\bar{B}\rangle = M^{SM}_{12} + M^{NP}_{12} = C_{B_q} e^{2i\phi_{B_q}} M^{SM}_{12}$

$\Gamma^{full}_{12} \sim \Gamma^{SM}_{12}$ (+ small effects due to penguins)

Notice that $\Gamma^{SM}_{12}/M^{SM}_{12}$ ~ real due to GIM suppression, since

$\Gamma^{SM}_{12} \propto (V_{tb}V_{tq}^*)^2 D^{cc}$ + GIM-suppressed

$M^{SM}_{12} \propto (V_{tb}V_{tq}^*)^2$

On the other hand,

$\mathrm{Arg}(M^{SM}_{12})_d = 2\beta \sim O(1)$

$\mathrm{Arg}(M^{SM}_{12})_s = -2\beta_s \sim O(10^{-2})$

What can we actually measure?

- $\Delta m_{B_q} = 2|M^{full}_{12}| = C_{B_q}\, \Delta m^{SM}_{B_q}$
- $\Delta\Gamma_q/\Delta m_{B_q} = \mathrm{Re}(\Gamma^{full}_{12}/M^{full}_{12}) \sim$

  $(\Delta\Gamma_q/\Delta m_{B_q})^{SM} \cos 2\phi_{B_q}/C_{B_q}$
- $A^q_{SL} = \mathrm{Im}(\Gamma^{full}_{12}/M^{full}_{12}) \sim -(\Delta\Gamma_q/\Delta m_{B_q})^{SM} \times$

  $\sin 2\phi_{B_q}/C_{B_q} = -\Delta\Gamma_q/\Delta m_{B_q} \tan 2\phi_{B_q}$
- $S_{J/\Psi K} \sim \sin 2(\beta+\phi_{B_d}),\ S_{J/\Psi\phi} \sim \sin 2(-\beta_s+\phi_{B_s})$

- Use tree-level processes to determine the CKM matrix and thus disentangle NP from SM contributions to B_q mixing:

  $|V_{ub}|$ and $|V_{cb}|$ from inclusive and exclusive semileptonic B decays

  γ from $B \to DK$ and α from $B \to \pi\pi, \rho\pi, \rho\rho$ decays

Results for the generalized UTA:

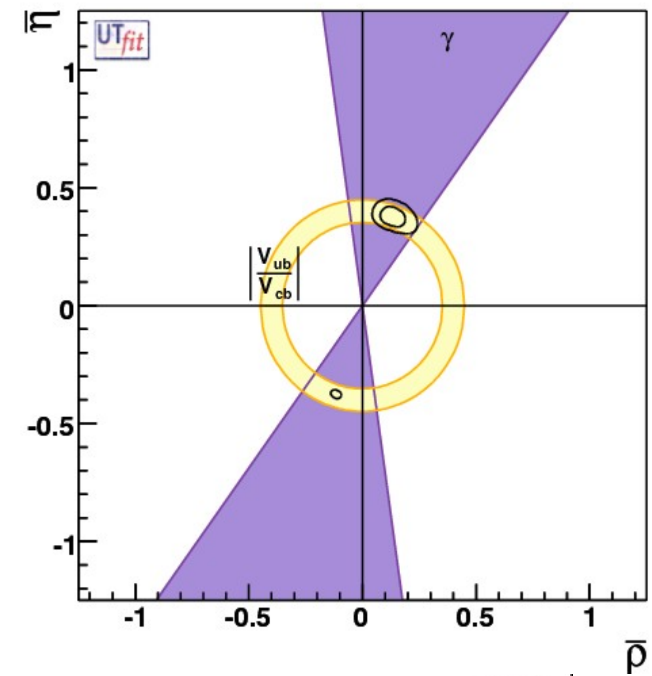
C_{Bd} = 0.90 ± 0.23

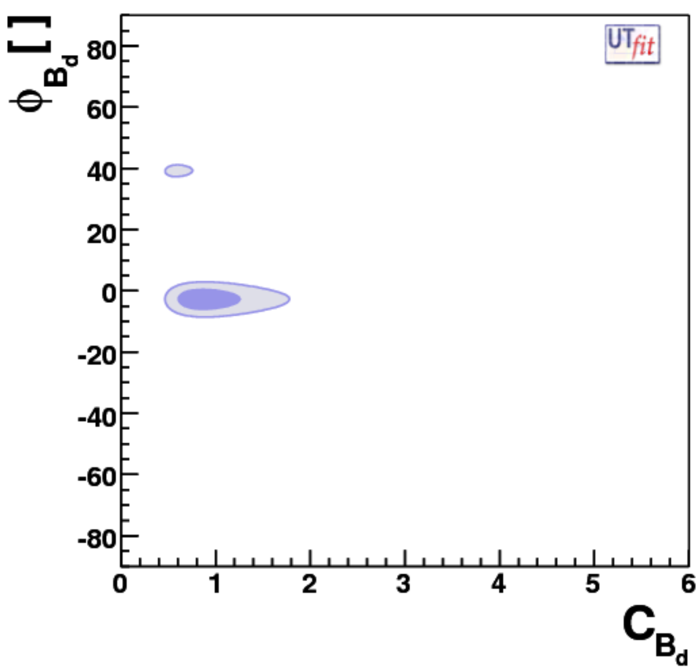
ϕ_{Bd} = (-2.7 ± 1.9)°

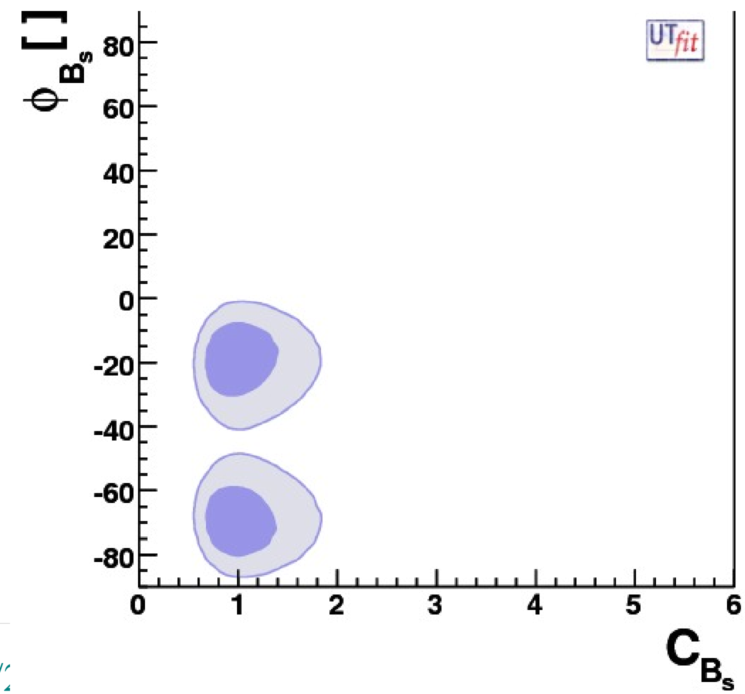
C_{Bs} = 0.99 ± 0.23

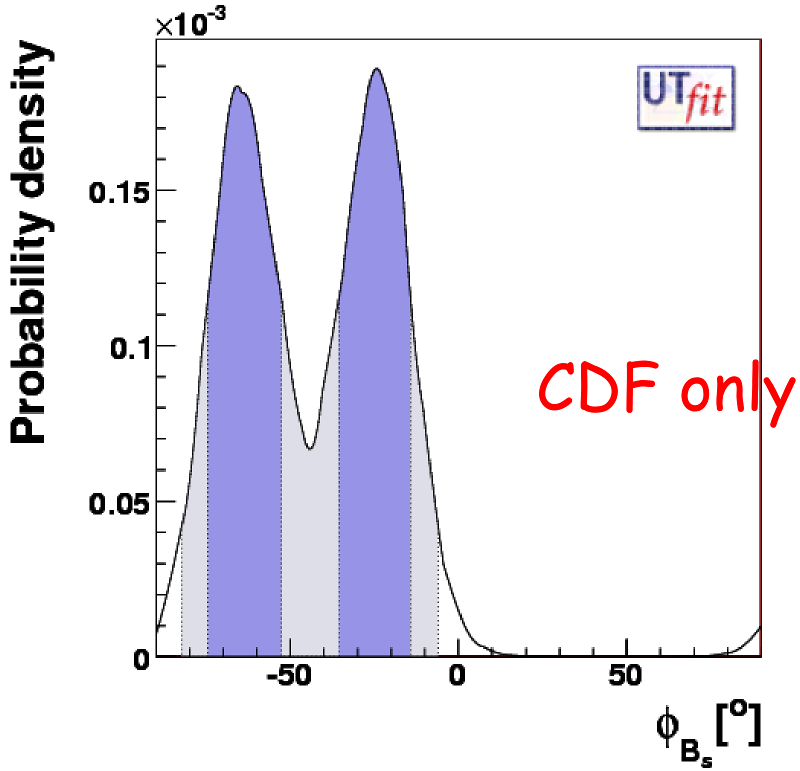
ϕ_{Bs} = (-18 ± 8)° U (-70 ± 7)°

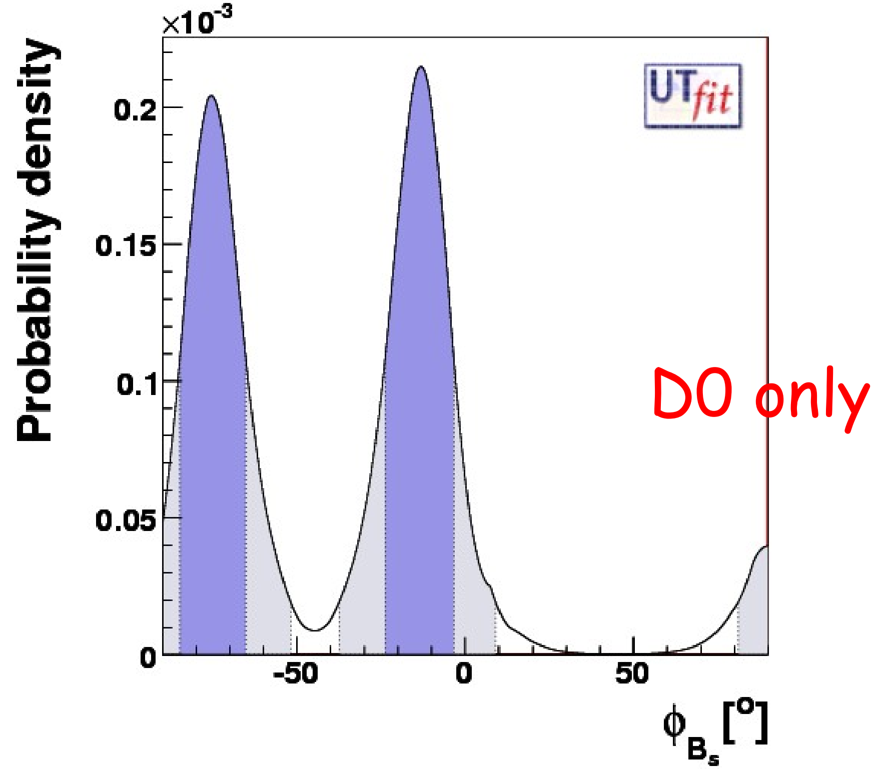
(2.9σ from the SM)

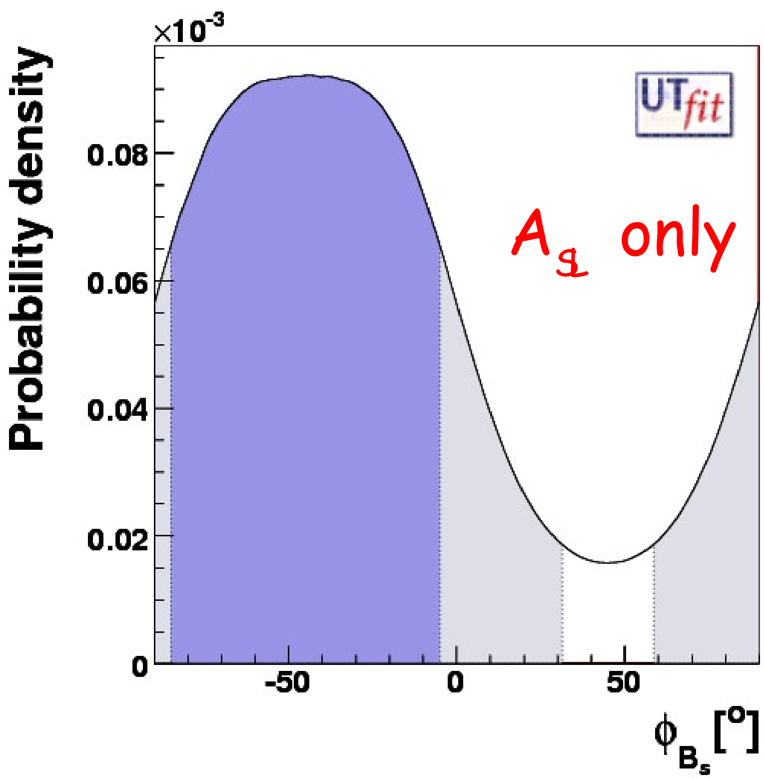







Probability density
×10^-3
UTfit
CDF only
ϕBs [o]


Probability density
×10^-3
UTfit
D0 only
ϕBs [o]


Probability density
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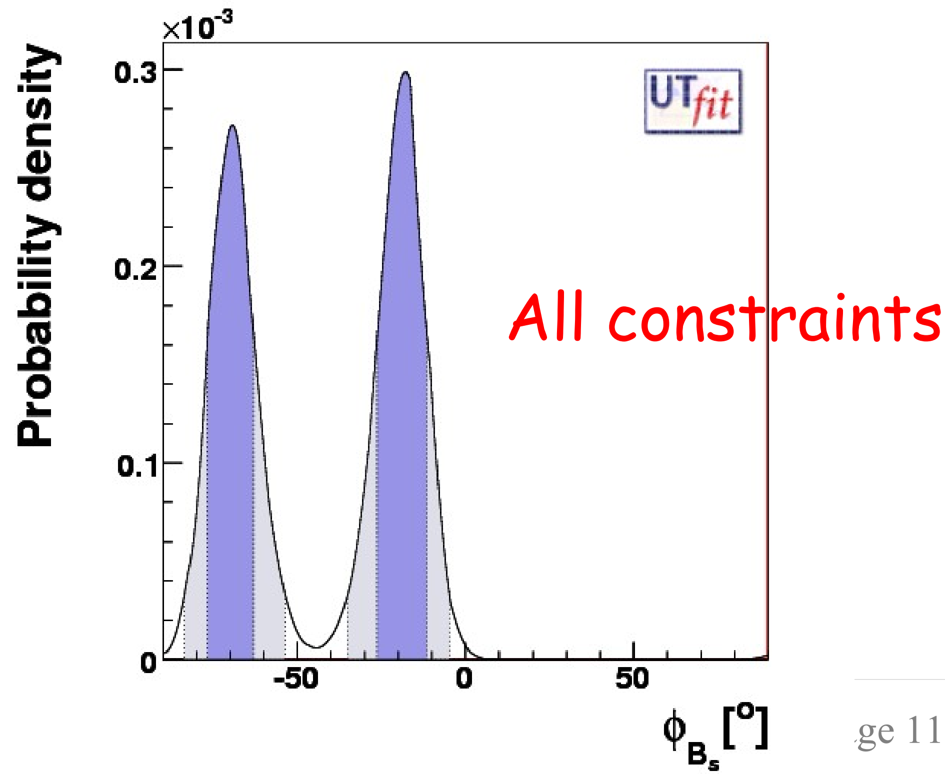
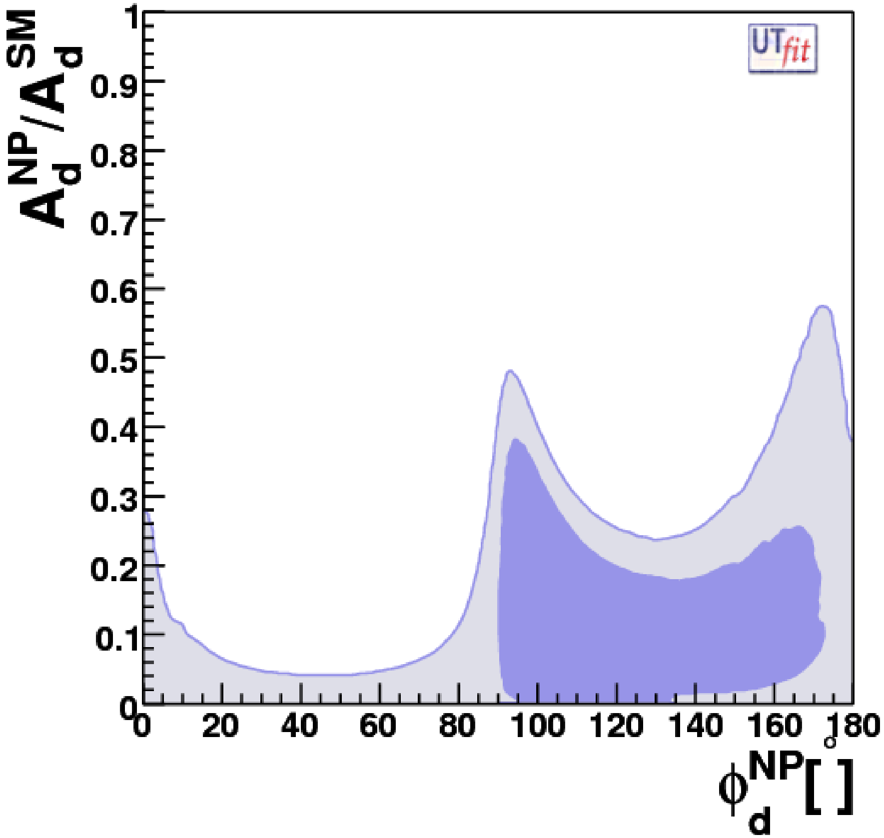
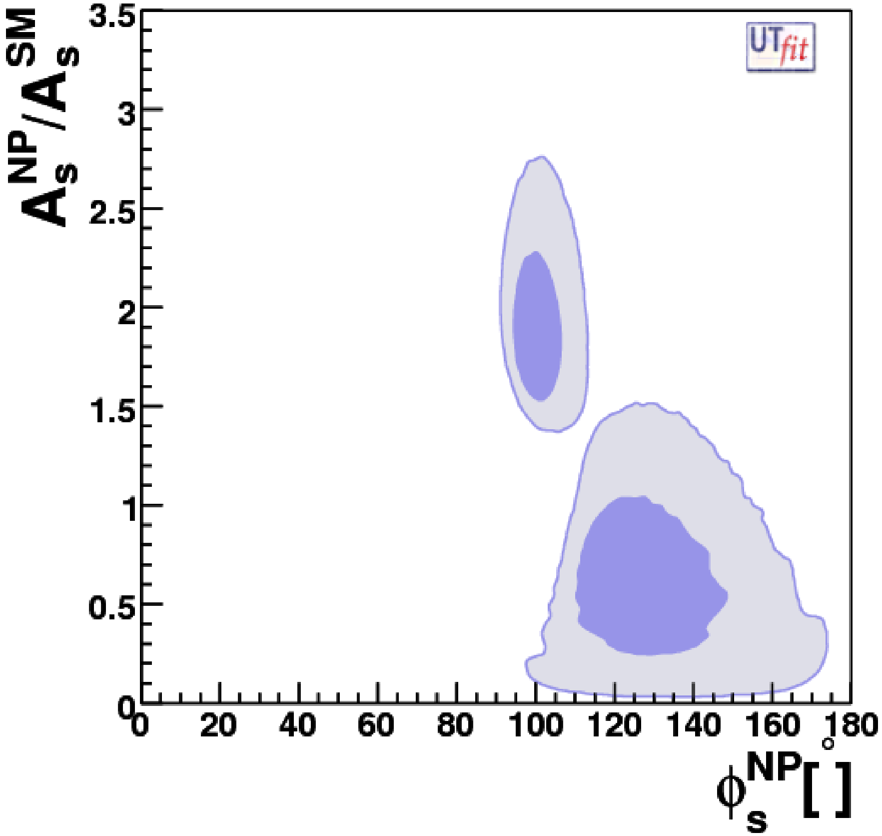
UTfit
Asl only
ϕBs [o]


Probability density
×10^-3
UTfit
All constraints
ϕBs [o]

NP IN B_q MIXING: RESULTS

- Strength of B_q mixings compatible with the SM with O(25%) uncertainty
- CP violation in B_d mixing compatible with the SM at < 2σ, NP contributions possible at the level of 2-3°
- Evidence of nonstandard CP violation in B_s mixing, with NP contributions ~ 20°, disfavoring Minimal Flavour Violation





Ratio of NP/SM contributions is < 40% @ 95% prob. in B_d mixing, and ~60% in B_s mixing (but 2σ range is very large)

See also Lunghi & Soni 08, Buras et al. 09

IMPLICATIONS ON NP

- 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.; …

NP IN PENGUINS I: B→Kπ

$$\mathcal{A}_{K^{\pm}\pi^{\mp}} \equiv \frac{N(\bar{B}^0 \to K^- \pi^+) - N(B^0 - K^+ \pi^-)}{N(\bar{B}^0 \to K^- \pi^+) + N(B^0 \to K^+ \pi^-)} = -0.094 \pm 0.018 \pm 0.008$$

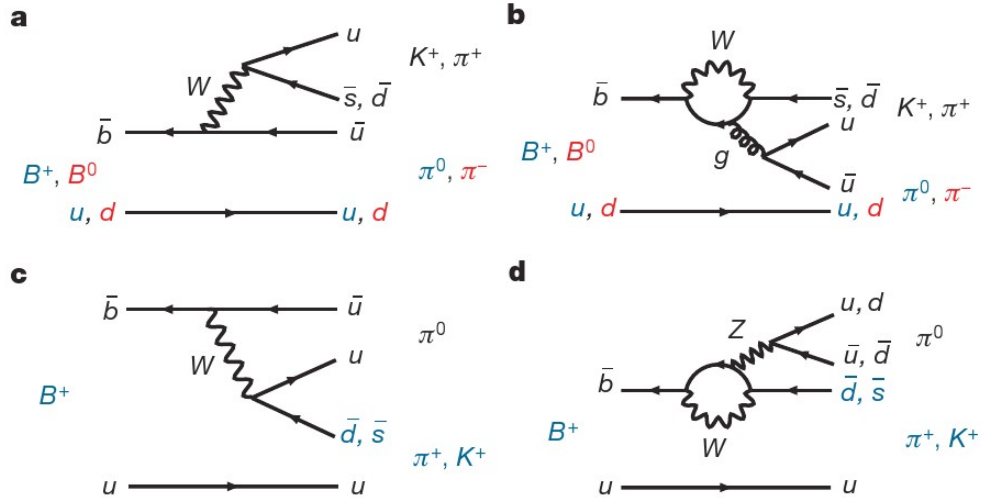
Belle collaboration
Nature 452,2008

$$\mathcal{A}_{K^{\pm}\pi^{0}} = +0.07 \pm 0.03 \pm 0.01$$

$$\Delta\mathcal{A} \equiv \mathcal{A}_{K^{\pm}\pi^{0}} - \mathcal{A}_{K^{\pm}\pi^{\mp}} = +0.164 \pm 0.037$$

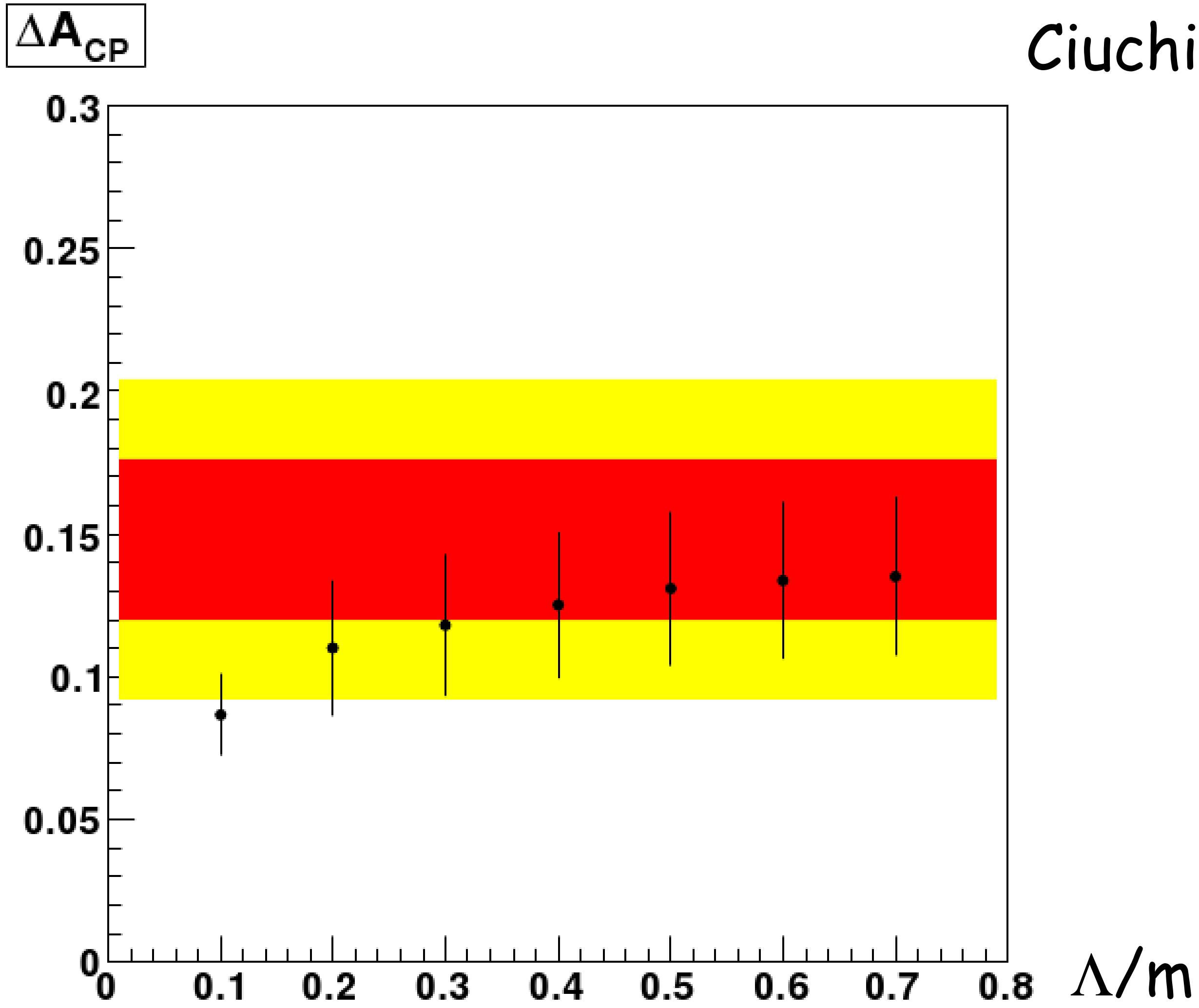
Is this new physics?

It could be but SM predictions depend on hadronic models



- Factorization in its various incarnations (QCDF, PQCD, SCET) gives results valid in the $m_b \to \infty$ limit
- Corrections to this limit are $O(\Lambda/m_b)$, but not calculable
- How much do the th predictions depend on power corrections?

Ciuchini et al. 08

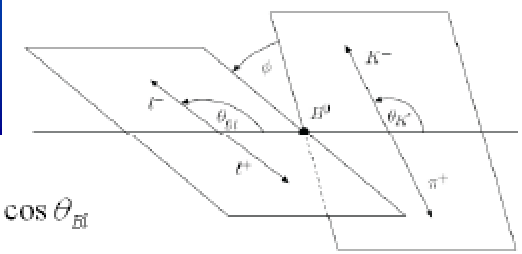


A good fit can be obtained either for $\Lambda/m \sim 0.3$ or for NP in $b \to sZ$ vertex. Inconclusive at present.

See also Buraisamy & Kagan 08, Li & Mishima 09

NP IN PENGUINS II: $B \to K^* l^+ l^-$

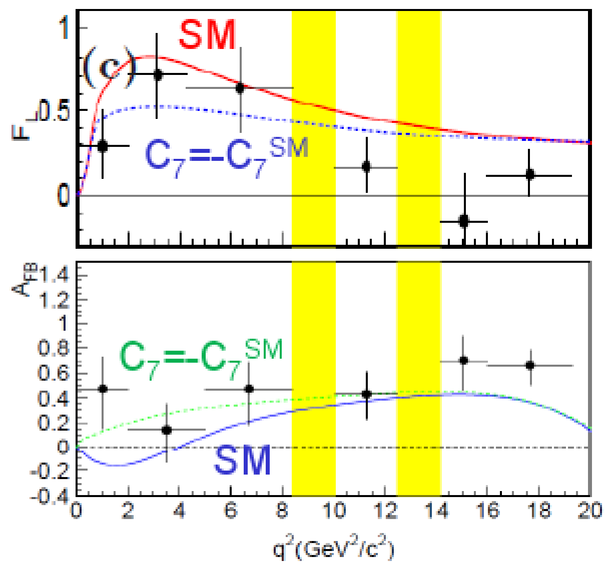
$B \to K^* ll$: FB Asymmetry



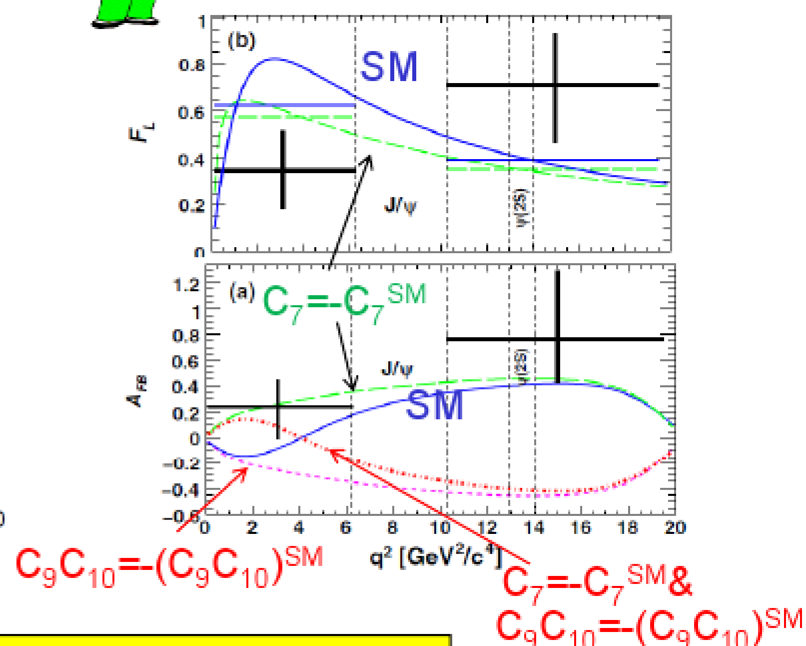
A_{FB} extracted from fits to

$$\frac{3}{4}F_L(1-\cos^2\theta_{Bl}) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_{Bl}) + A_{FB}\cos\theta_{Bl}$$

657 M BB,
submitted to PRL, arXiv: 0904.0770



384M BB,
PRD79, 031102(R) (2009)



A_{FB} exceeds SM ?

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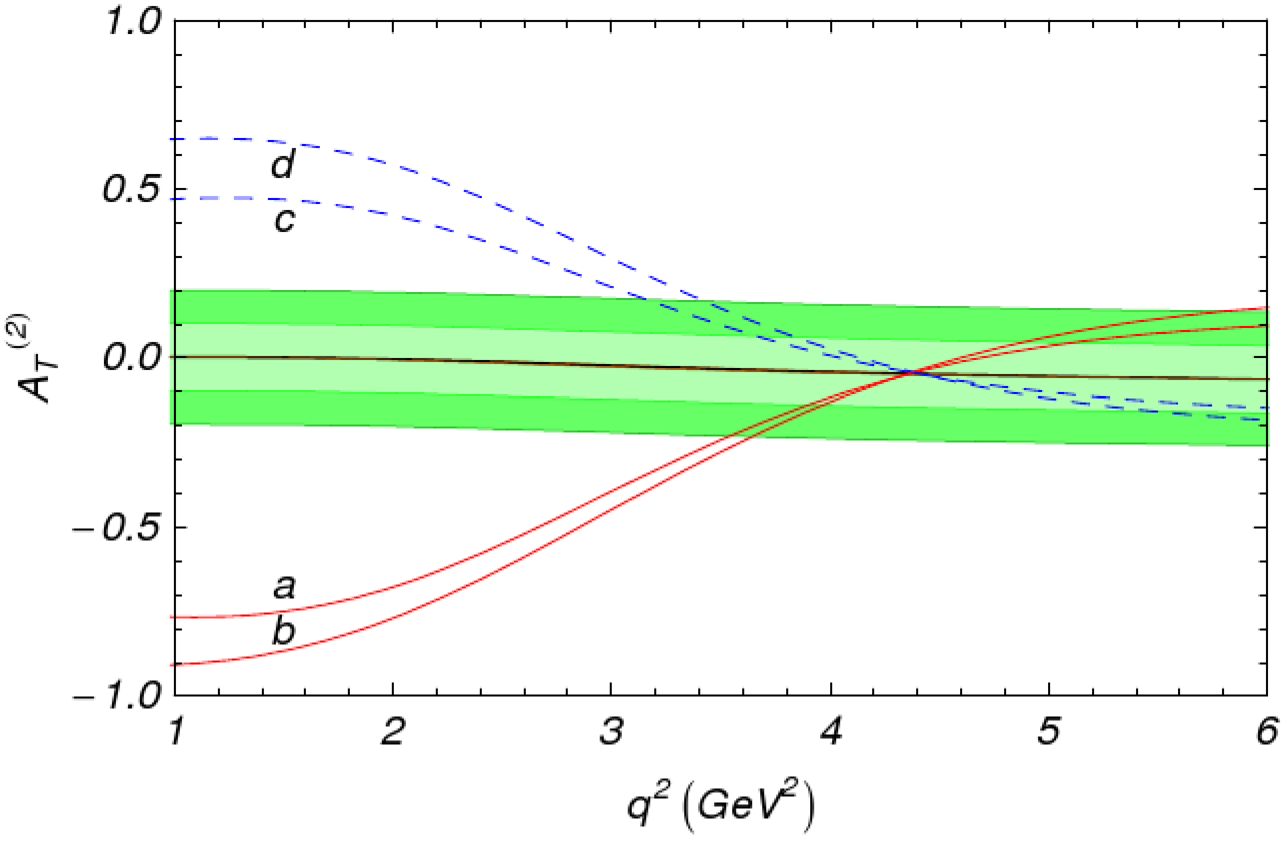
Iijima @ LP09

- A_{FB} suffers from form factor uncertainties, except for the zero point
- Cleaner asymmetries can be defined, but the problem of power corrections is always present:



Egede et al, arxiv:0807.2589

tanβ-enhanced NP in B decays

- For large tanβ, Y_b gets large and can strongly enhance chirality suppressed B decays: $b \to s\gamma$, $B \to \tau\nu$, $B_q \to \mu^+\mu^-$

$BR(B\to\tau\nu)_{SM} = (0.84\pm0.11)\ 10^{-4}$ UTfit coll. 09

$BR(B\to\tau\nu)_{exp} = (1.73\pm0.34)\ 10^{-4}$ (2.5σ)

$BR(B\to X_s\gamma)_{SM} = (3.15\pm0.23)\ 10^{-4}$ Misiak 09

$BR(B\to X_s\gamma)_{exp} = (3.50\pm0.14\pm0.10)\ 10^{-4}$

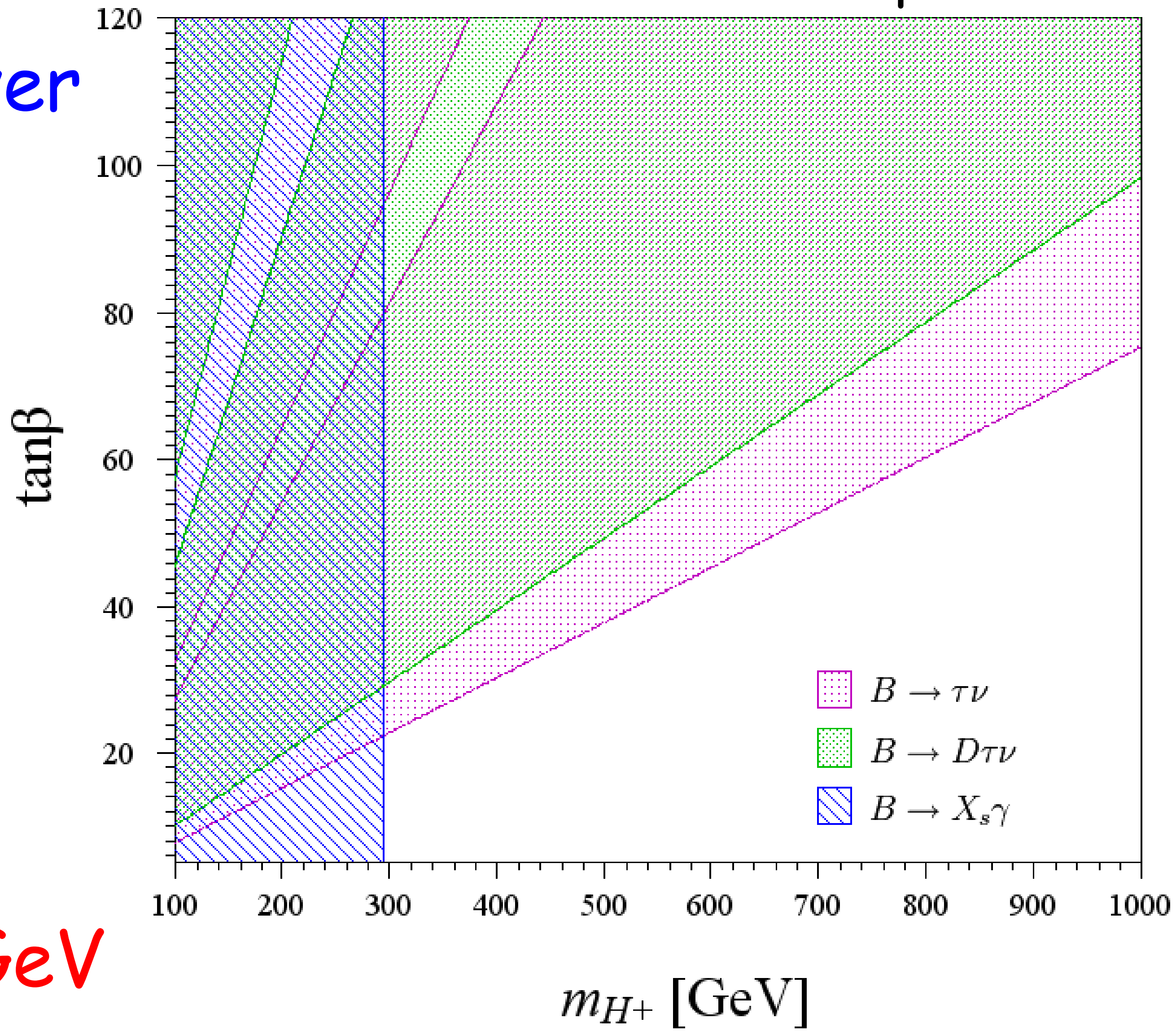
CONSTRAINTS ON 2HDMII

UTfit 09; see also Deschamps et al 09

- Ratio of 2HDM over SM:

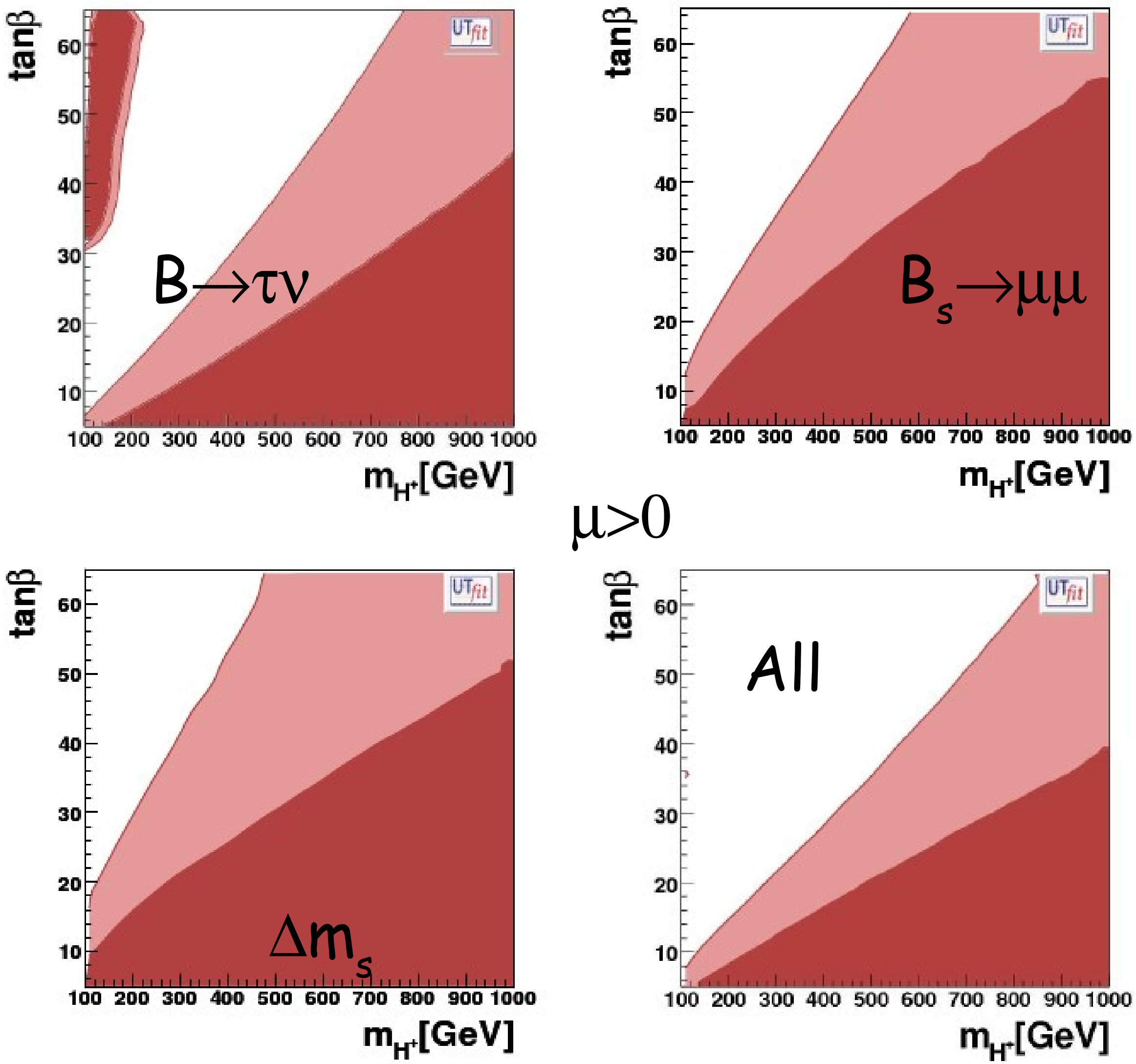
$$R_{2\mathrm{HDM}} = \left(1 - \tan^2\beta \frac{m_B^2}{m_{H^+}^2}\right)$$

- Fine-tuned region ruled out by semileptonic
- tanβ<7.5 m_H /100 GeV && m_H >295 GeV



CONSTRAINTS ON MFV-MSSM

- Consider the MSSM with MFV, O(TeV)
- Obtain $BR(B_s \to \mu^+\mu^-) < 19\ 10^{-9}$ $\sim 5\ BR(B_s \to \mu^+\mu^-)_{SM}$
- Stronger bounds for $\mu<0$



CONCLUSIONS

- B physics is naturally sensitive to any NP relevant for the hierarchy problem
- 2-3σ deviations from SM expectations seen in several processes:
  - CP violation in B_s mixing is at ~3σ, with negligible th uncertainty. If confirmed by Tevatron/LHCb, clear evidence of nonstandard CP violation!

- $B \to \tau\nu$ seems to exceed SM expectation by ~2σ, also disfavouring Minimal Flavour Violation models
- CPV in $b \to s$ penguins displays some deviation from SM expectations, albeit with a large theoretical uncertainty

- Need more data to check if this all consistently points to the theoretically well-motivated scenario of NP generating large effects in several $b \leftrightarrow s$ transitions

- In any case, the pessimistic MFV paradigm is presently disfavoured, implying that:
  - there are bright prospects for detecting indirect signals of NP in B decays;
  - we shouldn't really expect an msugra-like NP to show up at the LHC;
  - a global approach to NP searches, combining direct and indirect evidence, is mandatory in order to determine the NP Lagrangian