Probing the MSSM flavor structure with low energy CP violation

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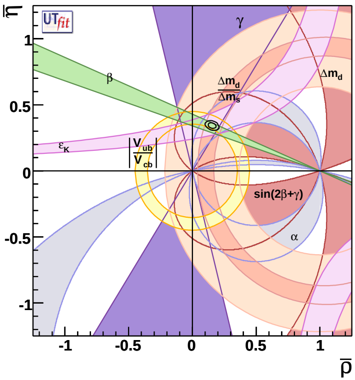
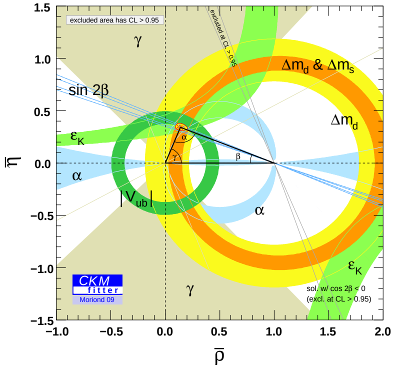
Outline

based on:

- WA, A.J. Buras and P. Paradisi
  Phys. Lett. B **669** (2008) 239
- WA, A.J. Buras, S. Gori, P. Paradisi and D. Straub
  to appear very soon...

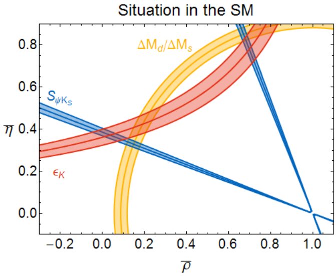
CP Violation in the SM

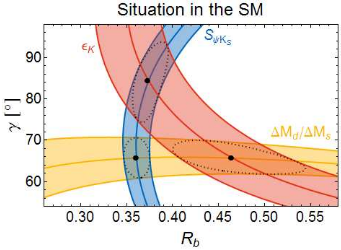




Hints for New Sources of CP Violation?

1. Tensions in the Unitarity Triangle
   Lunghi, Soni '08,'09; Buras, Guadagnoli '08,'09





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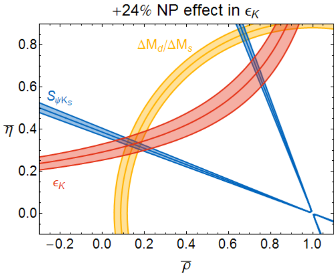

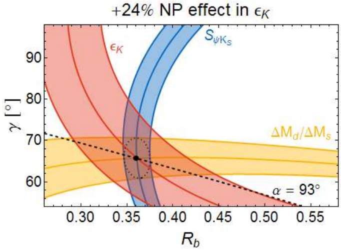

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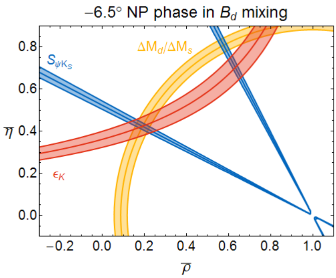

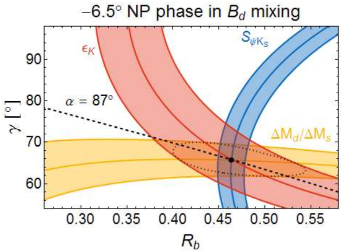

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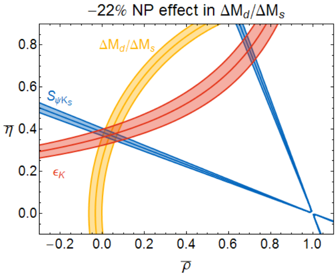

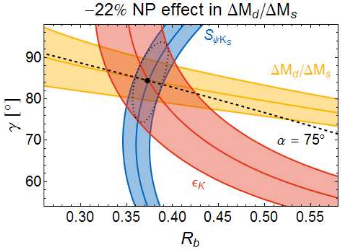

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2 $\sin 2\beta$ from $B \to \psi K_S$ and $B \to \phi(\eta')K_S$

- In the SM: $S_{\psi K_S} = S_{\phi K_S} = S_{\eta' K_S} = \sin 2\beta$
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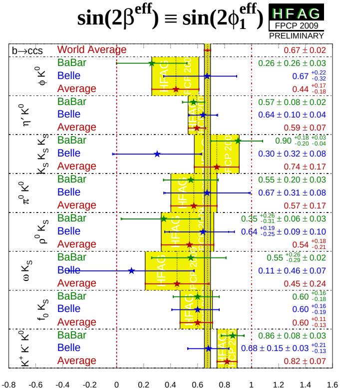

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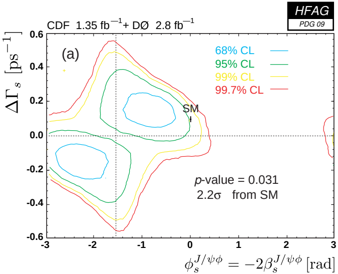
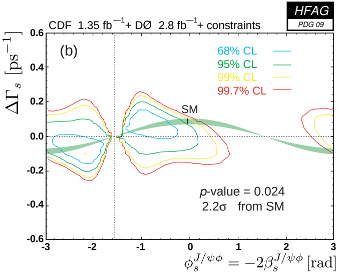
3 CP Violation in B_s mixing

- Recent data from CDF and D0 seem to indicate large NP effects in $S_{\psi\phi}$
  $S_{\psi\phi} = \sin 2(\beta_s + \Phi^{NP}_{B_s}) = 0.81^{+0.12}_{-0.32}$, $\beta_s \simeq 1^\circ$
- Large B_s mixing phase?
- LHCb will give the answer





How to generate large effects in $S_{\psi\phi}$?

CP Violating Low Energy Observables

$\Delta F = 0$

$\Delta F = 1$

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- Time dependent CP asymmetries in $B_d \to \phi K_S$ and $B_d \to \eta' K_S$, $S_{\phi K_S}$ and $S_{\eta' K_S}$

A Flavor Blind MSSM with CP Violating Phases

In a flavor blind MSSM (FBMSSM) there are no additional flavor structures apart from the CKM matrix. In particular, we assume

- universal squark masses
- hierarchical and flavor diagonal trilinear couplings
- and allow for flavor conserving but CP violating phases

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Within this setup large NP effects arise dominantly through the magnetic and chromomagnetic dipole operators

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b \bar{s}_L \sigma^{\mu\nu} F_{\mu\nu} b_R \ ,$$

$$\mathcal{O}_8 = \frac{g_s}{16\pi^2} m_b \bar{s}_L \sigma^{\mu\nu} G_{\mu\nu} b_R$$

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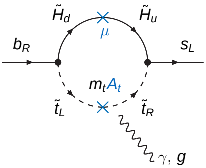
$$C_{7,8} \propto \mu A_t$$



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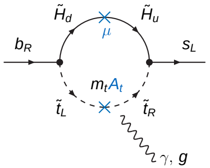


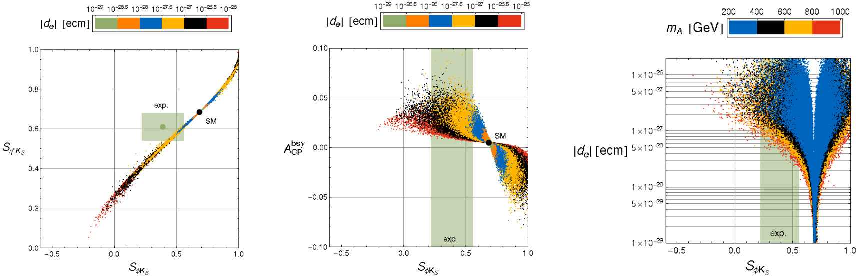
→ Interesting correlated effects in CP violating observables

WA, Buras, Paradisi '08

For analyses of similar frameworks see:

Baek, Ko '99; Bartl, Gajdosik, Lunghi, Masiero, Porod, Stremnitzer, Vives '01; Ellis, Lee, Pilaftsis '07; Mercolli, Smith '09

Phenomenology of CP Violation in the FBMSSM



- CP violating $\Delta F = 0$ and $\Delta F = 1$ dipole amplitudes can be strongly modified
- $S_{\phi K_S}$ and $S_{\eta' K_S}$ can simultaneously be brought in agreement with the data
- sizeable and correlated effects in $A_{CP}^{bs\gamma} \simeq 1\% - 6\%$
- lower bounds on the electron and neutron EDMs at the level of $d_{e,n} \gtrsim 10^{-28}$ecm
- large and correlated effects in the CP asymmetries in $B \to K^* \mu^+ \mu^-$ (WA, Ball, Bharucha, Buras, Straub, Wick)

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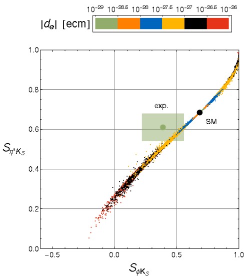

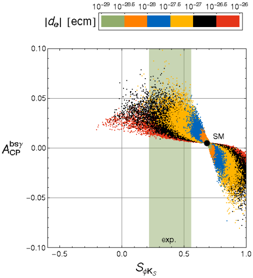

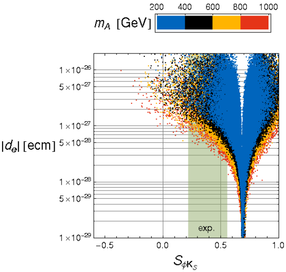

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- the leading NP contributions to $\Delta F = 2$ amplitudes are not sensitive to the new phases of the FBMSSM
- CP violation in meson mixing is SM like
- i.e. small effects in $S_{\psi\phi}$, $S_{\psi K_S}$ and ϵ_K
- in particular: $0.03 < S_{\psi\phi} < 0.05$

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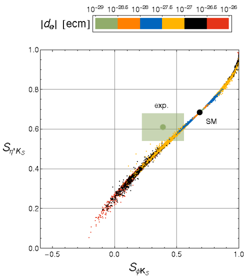

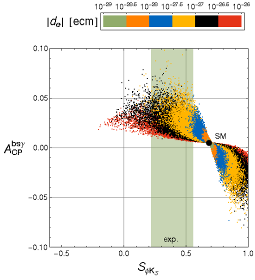

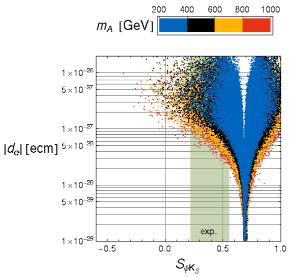

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A combined study of all these observables and their correlations constitutes a very powerful test of the FBMSSM

Introducing New Sources of Flavor Violation

- Soft squark masses and trilinear couplings can contain additional flavor structures beyond the CKM matrix.
- Such structures lead to flavor off-diagonal entries in the squark masses.

Convenient parametrization through mass insertions

$$M_q^2 = \tilde{m}^2 \mathbb{1} + \tilde{m}^2 \delta_q$$

$$\delta_q = \begin{pmatrix} \delta_q^{LL} & \delta_q^{LR} \\ \delta_q^{RL} & \delta_q^{RR} \end{pmatrix} \quad , \quad q = u, d$$

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Complex mass insertions lead to flavor and CP violating gluino-quark-squark interactions that will generate the dominant contributions to FCNCs

The largest gluino contributions to the mixing amplitudes are generated if both LL and RR mass insertions are present simultaneously

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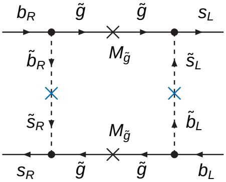
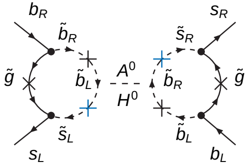


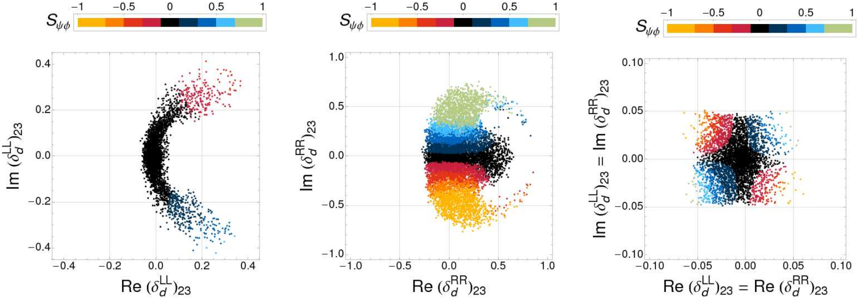
$$\propto \frac{\alpha_s^2}{\tilde{m}^2} (\delta_d^{LL})_{32} (\delta_d^{RR})_{32}$$



$$\propto \frac{\alpha_2}{4\pi} \frac{\alpha_s^2}{M_A^2} \frac{m_b^2}{M_W^2} \tan^4\beta \times (\delta_d^{LL})_{32} (\delta_d^{RR})_{32}$$

The Impact of Mass Insertions on $S_{\psi\phi}$

* MSUGRA spectrum: $m_0 < 300\text{GeV}$, $m_{12} < 200\text{GeV}$, $|A_0| < 3m_0$, $5 < \tan\beta < 15$ and $\mu > 0$
  Mass insertions defined at the low scale



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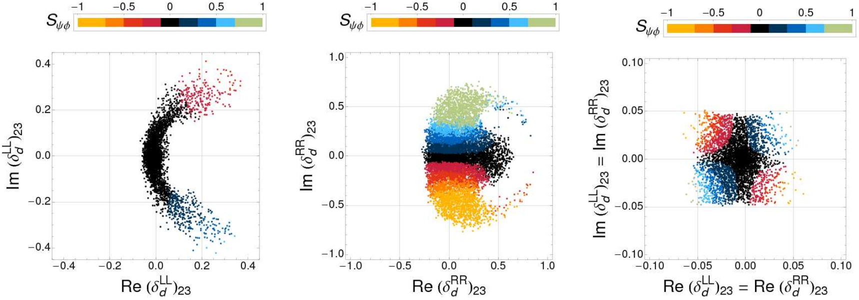

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There are many flavor models that predict such structures

- Abelian: Nir, Seiberg '93; Nir, Raz '02; Agashe, Carone '03; ...
- Non Abelian: Barbieri, Hall, Romanino '97; Carone, Hall, Moroi '97; ... Ross, Velasco-Sevilla, Vives '04; ...

Concrete Examples of Flavor Models

Example: Agashe, Carone '03 (AC)

- Abelian flavor model based on a $U(1)$ horizontal symmetry
- "remarkable level of alignment"

$$(\delta_d^{LL}) \sim \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & \lambda^2 \\ 0 & \lambda^2 & 1 \end{pmatrix}$$

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Expected phenomenology:

- Small effects in $b \to d$ and $s \to d$ transitions
- Large effects in D_0-$\bar{D}_0$ mixing (general feature of abelian models)
- Large effects in B_s-$\bar{B}_s$ mixing (in particular in $S_{\psi\phi}$ for complex δs)

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Example: Ross, Velasco-Sevilla, Vives '04 (RVV)

- Non abelian flavor model based on a $SU(3)$ flavor symmetry
- 1st and 2nd generation of squarks approximately degenerate

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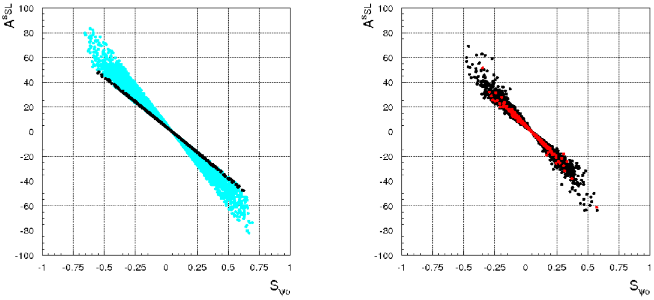
Expected phenomenology:

- Moderate effects in $b \to d$ and $s \to d$ transitions (large effects in ϵ_K)
- Small effects in D_0-$\bar{D}_0$ mixing
- Sizeable effects in B_s-$\bar{B}_s$ mixing (in particular in $S_{\psi\phi}$ for complex δs)

Numerical Results $^{(*)}$

AC



RVV

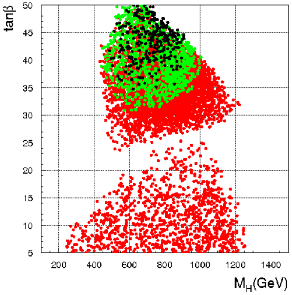
- Both models can have large effects in $S_{\psi\phi}$
- Strong (model independent) correlation with the semileptonic asymmetry A^s_{SL} (Ligeti, Papucci, Prerez '06)

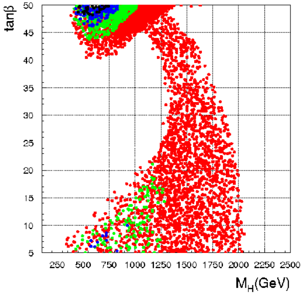
$^{(*)}$ MSUGRA spectrum: $5 < \tan\beta < 50$, $m_0 < 1\text{TeV}$, $m_{12} < 1\text{TeV}$, $A_0 = 0$, $\mu > 0$

Flavor structures implemented at the GUT scale

Numerical Results $^{(*)}$

AC





RVV

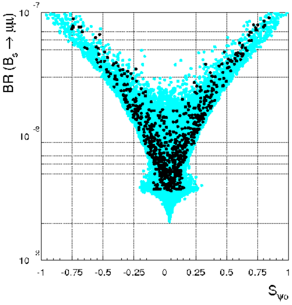
- The huge effects in $S_{\psi\phi}$ arise in the large $\tan\beta$ regime through Higgs penguin contributions

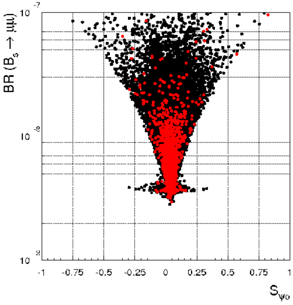
$^{(*)}$ MSUGRA spectrum: $5 < \tan\beta < 50$, $m_0 < 1$TeV, $m_{12} < 1$TeV, $A_0 = 0$, $\mu > 0$

Flavor structures implemented at the GUT scale

Numerical Results $^{(*)}$

AC





RVV

- The huge effects in $S_{\psi\phi}$ arise in the large $\tan\beta$ regime through Higgs penguin contributions
- Correlations with the rare decay $B_s \to \mu^+\mu^-$

$^{(*)}$ MSUGRA spectrum: $5 < \tan\beta < 50$, $m_0 < 1$TeV, $m_{12} < 1$TeV, $A_0 = 0$, $\mu > 0$

Flavor structures implemented at the GUT scale

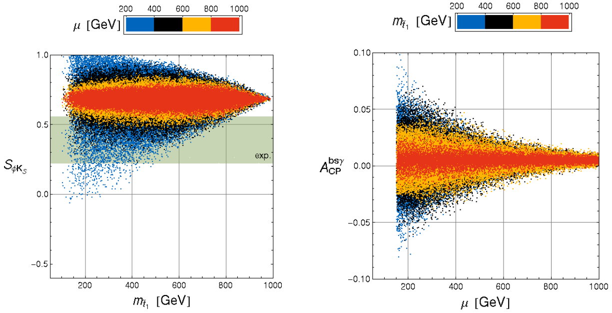
Summary: “Flavor DNA”

	GMSSM	AC	RVV	δ_{LL} only	FBMSSM
$D^0 - \bar{D}^0$ mixing	★★★	★★★	★	★	★
ϵ_K	★★★	★	★★★	★	★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★
$S_{\phi K_S}$, $S_{\eta' K_S}$	★★★	★★★	★★	★★★	★★★
$A_{CP}^{bs\gamma}$	★★★	★	★	★★★	★★★
$\langle A_{7,8} \rangle (B \to K^* \mu^+ \mu^-)$	★★★	★	★★	★★★	★★★
$\langle A_9 \rangle (B \to K^* \mu^+ \mu^-)$	★★★	★	★★	★	★
$B_s \to \mu^+ \mu^-$	★★★	★★★	★★★	★★★	★★★
$B \to K^{(*)} \nu \bar{\nu}$	★★	★	★	★	★
$K \to \pi \nu \bar{\nu}$	★★★	★	★★	★	★
d_e, d_n	★★★	★★★	★★	★★	★★★

★★★: large effects, ★★: medium effects, ★: small effects

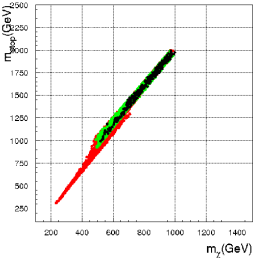
Back Up

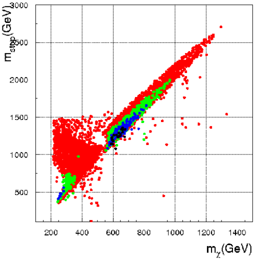
FBMSSM Implications for Direct Searches



- $S_{\phi K_S} \simeq 0.4$ implies $\boldsymbol{\mu} \lesssim$ **600GeV** and $\boldsymbol{m_{\tilde{t}_1}} \lesssim$ **700GeV**
- similarly, large non standard effects in $A_{CP}^{bs\gamma} \gtrsim 2\%$ imply $\boldsymbol{\mu} \lesssim$ **600GeV** and $\boldsymbol{m_{\tilde{t}_1}} \lesssim$ **800GeV**
- stops and Higgsinos lie well **within the reach of LHC**

AC





RVV

- Sizeable effects in $S_{\psi\phi}$ are possible in a large region of parameter space
- Even **sparticles beyond the LHC reach** can lead to **visible departures of $S_{\psi\phi}$ from its SM prediction**