Low Energy Probes of CP Violation in a Flavor Blind MSSM

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Outline

based on:

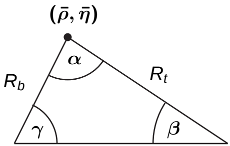
WA, Andrzej Buras and Paride Paradisi
arXiv:0808.0707v1 [hep-ph]

WA, Andrzej Buras and Paride Paradisi
in preparation

Apart from the QCD θ term, the only source for CP violation in the SM is the phase in the CKM matrix.

CP violation from the CKM matrix can be visualized by Unitarity Triangles e.g.

$$V_{ub}V_{ud}^* + V_{cb}V_{cd}^* + V_{tb}V_{td}^* = 0$$



CP violation in the SM

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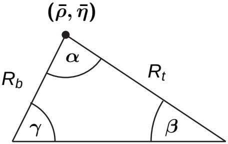
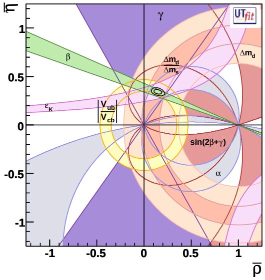
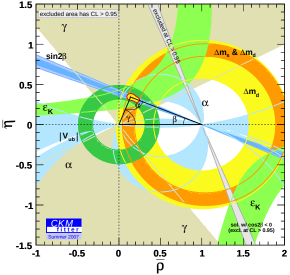
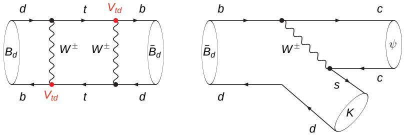


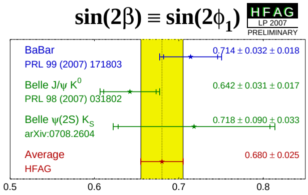




Impressive confirmation of the CKM picture for CP violation

1 CP Asymmetry in $B \to \psi K_S$ and $\sin 2\beta$



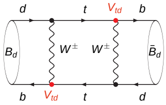


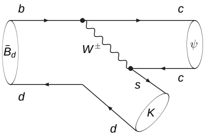
- Tree level decay $\to$ sensitivity to the phase of the mixing amplitude without NP in the decay amplitude
- in SM: $\text{Arg}(M_{12}^d) = \text{Arg}(V_{td}^2) = 2\beta$

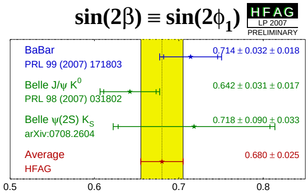
$$\sin 2\beta \overset{\text{SM}}{=} S_{\psi K_S}^{\text{exp.}} = 0.680 \pm 0.025$$

Hints for new sources of CP violation?

1 CP Asymmetry in $B \to \psi K_S$ and $\sin 2\beta$







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- In the SM also loop induced modes like $B \longrightarrow \phi K_S$ and $B \longrightarrow \eta' K_S$ give the same value

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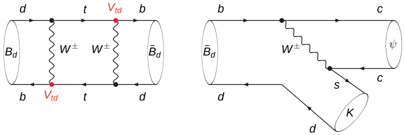

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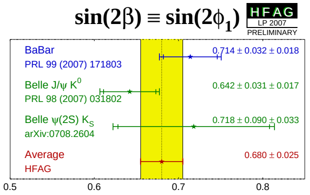
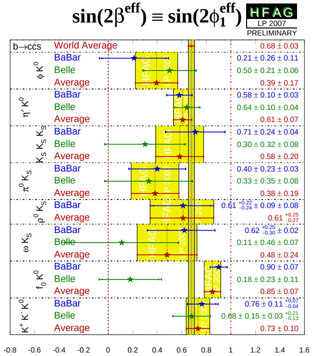
$$S^{\text{SM}}_{\phi K_S} = S^{\text{SM}}_{\eta' K_S} = S^{\text{SM}}_{\psi K_S} = \sin 2\beta$$

$$S^{\text{exp.}}_{\phi K_S} = 0.39 \pm 0.17 \qquad S^{\text{exp.}}_{\eta' K_S} = 0.61 \pm 0.07$$

$\Rightarrow$ New Phases in decays?





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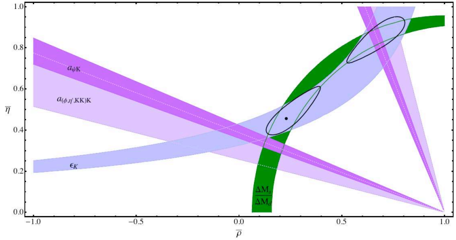

Lunghi, Soni '08

2 Tensions in the Unitarity Triangle

perform UT fit including only ϵ_K and $\Delta M_d / \Delta M_s$ using

- non perturbative parameter
  $B_K = 0.72 \pm 0.013 \pm 0.037$ (Antonio et al. '07)
- additional effective suppression factor in ϵ_K:
  $\kappa_\epsilon = 0.92$ (Buras, Guadagnoli '08)

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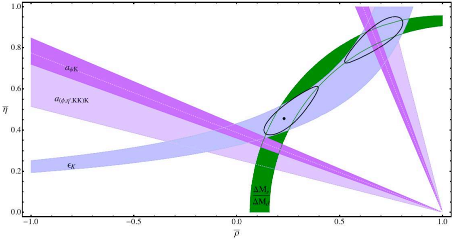

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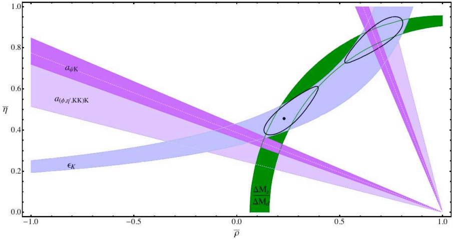
$\Rightarrow$ NP phase in B_d mixing?

$\Rightarrow$ Additional CP violation in K mixing?



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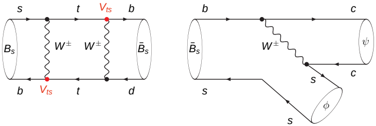
3 $B_s \to \psi\phi$ and $\sin 2\beta_s$



$$S_{\psi\phi} = \sin 2(\beta_s + \Phi^{NP}_{B_s}) \ , \quad \beta_s \simeq 1^\circ$$

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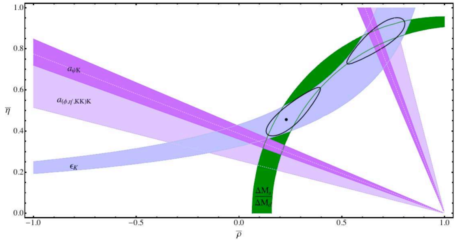

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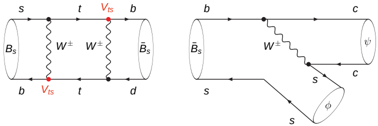
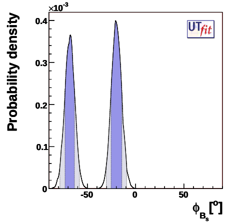


$$S_{\psi\phi} = \sin 2(\beta_s + \Phi^{NP}_{B_s}) \ , \ \beta_s \simeq 1^\circ$$

$$\Phi^{NP}_{B_s} = (19.9^\circ \pm 5.6^\circ) \cup (68.2^\circ \pm 4.9^\circ)$$

$\Rightarrow$ Large B_s mixing phase?



Bona et al. '08

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 and diagonal trilinear couplings.

$\Rightarrow$ no gluino contributions to FCNCs

Parameters of a flavor blind MSSM

- Higgs sector: $\tan\beta$, $M_{H^\pm}$
- Higgsino mass: μ
- Gaugino masses: M_1, M_2, M_3
- squark masses: m_Q^2, m_U^2, m_D^2
- trilinear couplings: A_d, A_s, A_b, A_u, A_c, A_t

The Higgsino and Gaugino masses as well as the trilinear couplings can in general be complex.

Observables only depend on particular combinations of complex parameters.

A Flavor Blind MSSM with CP Violating Phases

Main role is played by one complex parameter combination

$$\mu A_t$$

$\longrightarrow$ Interesting correlated effects in CP violating observables

WA, Buras, Paradisi '08

Most important constraints: EDMs and $b \to s\gamma$

$$\mathcal{BR}[B \to X_s\gamma]^{\text{exp.}} = (3.52 \pm 0.25) \times 10^{-4}$$ HFAG '08

$$\mathcal{BR}[B \to X_s\gamma]^{\text{SM}} = (3.15 \pm 0.23) \times 10^{-4}$$ Misiak et al. '06

- $b \to s\gamma$ amplitude is helicity suppressed
- typically large NP effects, even in a FBMSSM with low $\tan\beta$

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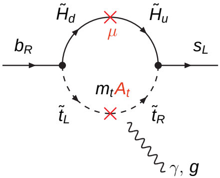
$$\mathcal{C}_{7,8}^{\tilde{\chi}^\pm}(\mu_{\text{SUSY}}) \simeq \frac{m_t^2}{\bar{m}_{\tilde{t}}^4} A_t \mu \tan\beta \times f_{7,8}\left(\frac{|\mu|^2}{\bar{m}_{\tilde{t}}^2}\right)$$



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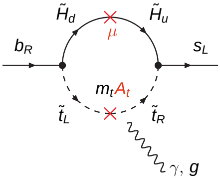

$$\mathcal{BR}[B \to X_s\gamma] \propto |\mathcal{C}_7^{\text{SM}}(m_b) + \mathcal{C}_7^{\text{NP}}(m_b)|^2 \simeq |\mathcal{C}_7^{\text{SM}}(m_b)|^2 + 2\text{Re}(\mathcal{C}_7^{\text{SM}}(m_b)\mathcal{C}_7^{\text{NP}}(m_b))$$

$\to$ Constraint on $\text{Re}(\mu A_t)$

Most important constraints: EDMs and $b \to s\gamma$

$d_e^{\text{exp.}} \lesssim 1.6 \times 10^{-27} e\text{cm}$

$d_n^{\text{exp.}} \lesssim 2.9 \times 10^{-26} e\text{cm}$

$d_e^{\text{SM}} \simeq 10^{-38} e\text{cm}$

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- In the MSSM, EDMs can be induced already at the 1loop level
  $\longrightarrow$ typically tight constraints on CP violating phases

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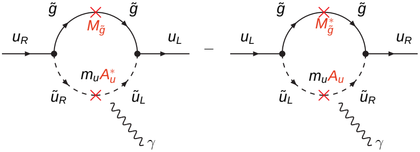

$$d_u \simeq \frac{e g_s^2}{16\pi^2} m_u \frac{\text{Im}(M_{\tilde{g}} A_u^*)}{\bar{m}_{\tilde{u}}^4} F\left(\frac{|M_{\tilde{g}}|^2}{\bar{m}_{\tilde{u}}^2}\right)$$

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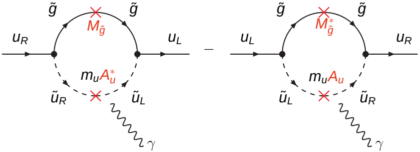

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Constraints can be avoided by e.g.

- hierarchical trilinear couplings $A_{u,c} \ll A_t$, $A_{d,s} \ll A_b$
- heavy 1st and 2nd generation of squarks

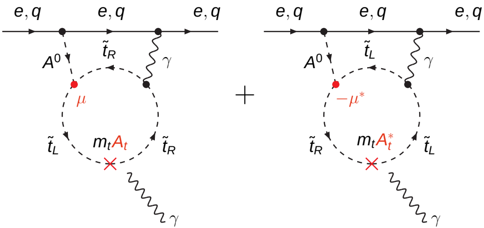
But: sizeable effects in flavor observables still possible, as 3rd generation squarks enter

Most important constraints: EDMs and $b \to s\gamma$

Chang, Keung, Pilaftsis '98

2-loop Barr-Zee type diagrams generating both lepton and quark EDMs

- sensitive to 3rd generation of squarks
- decouple with $1/\max(M_{A^0}^2, m_{\tilde{t}}^2)$



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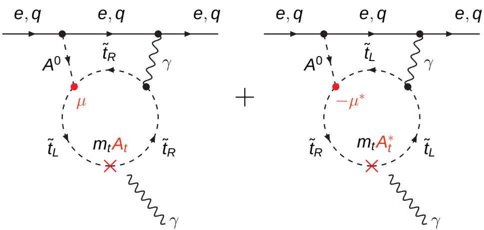

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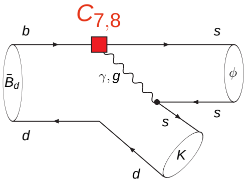
CP Asymmetries in $B \to \phi K_S$ and $B \to \eta' K_S$

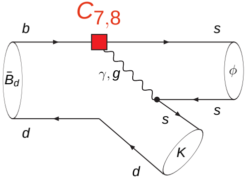


Time dependent CP Asymmetries in decays of neutral B mesons to final CP Eigenstates

$$A_{CP}(t, \phi K_S) = \frac{\Gamma(B(t) \to \phi K_S) - \Gamma(\bar{B}(t) \to \phi K_S)}{\Gamma(B(t) \to \phi K_S) + \Gamma(\bar{B}(t) \to \phi K_S)}$$

$$= C_{\phi K_S} \cos(\Delta M_d t) - S_{\phi K_S} \sin(\Delta M_d t)$$

$$S_{\phi K_S} = -\frac{2 \mathrm{Im}(\xi_{\phi K_S})}{1 + |\xi_{\phi K_S}|^2} \ , \ \ \xi_{\phi K_S} = e^{-i \mathrm{Arg}(M_{12}^d)} \frac{A(\bar{B} \to \phi K_S)}{A(B \to \phi K_S)}$$



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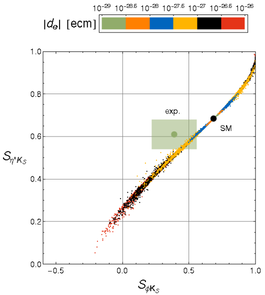

ABP'08

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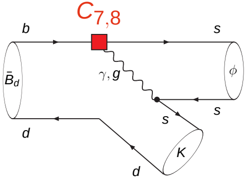
- sizeable, correlated effects in $S_{\phi K_S}$ and $S_{\eta' K_S}$
- larger effects in $S_{\phi K_S}$ as indicated by the data



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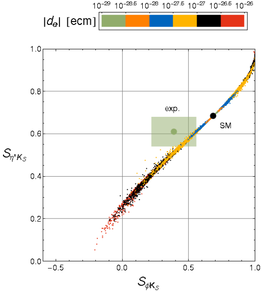
- sizeable, correlated effects in $S_{\phi K_S}$ and $S_{\eta' K_S}$
- larger effects in $S_{\phi K_S}$ as indicated by the data
- for $S_{\phi K_S} \simeq 0.4$, lower bounds on the electron and neutron EDMs:

$$d_e \gtrsim 5 \times 10^{-28} \text{ecm} \quad , \quad d_n \gtrsim 8 \times 10^{-28} \text{ecm}$$



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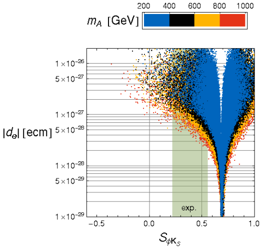
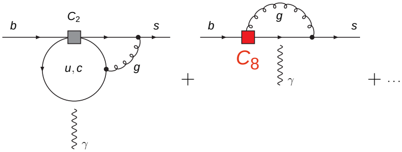


Direct CP Asymmetry in $b \to s\gamma$

Soares '91; Kagan, Neubert '98

$$A_{CP}^{bs\gamma} = \frac{\Gamma(\bar{B} \to X_s\gamma) - \Gamma(B \to X_{\bar{s}}\gamma)}{\Gamma(\bar{B} \to X_s\gamma) + \Gamma(B \to X_{\bar{s}}\gamma)}$$



- arises first at order α_s
- doubly Cabibbo and GIM suppressed in the SM
- sizeable value would be clear signal for New Physics

$A_{CP}^{bs\gamma}(\text{SM}) \simeq (0.44^{+0.24}_{-0.14})\%$ Hurth, Lunghi, Porod '03

$A_{CP}^{bs\gamma}(\text{exp.}) \simeq (0.4 \pm 3.6)\%$ HFAG

$$A_{CP}^{bs\gamma} \simeq \frac{\alpha_s}{|C_7|^2}\left(b_{27}\text{Im}(C_2 C_7^*) + b_{87}\text{Im}(C_8 C_7^*) + b_{28}\text{Im}(C_2 C_8^*)\right)$$

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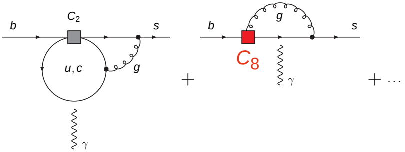
Soares '91; Kagan, Neubert '98

$$A_{CP}^{bs\gamma} = \frac{\Gamma(\bar{B} \to X_s\gamma) - \Gamma(B \to X_{\bar{s}}\gamma)}{\Gamma(\bar{B} \to X_s\gamma) + \Gamma(B \to X_{\bar{s}}\gamma)}$$



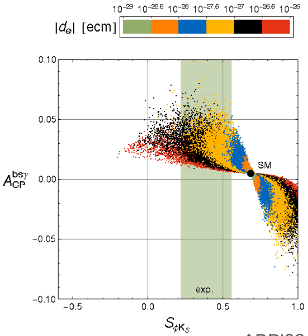
- arises first at order α_s
- doubly Cabibbo and GIM suppressed in the SM
- sizeable value would be clear signal for New Physics

$A_{CP}^{bs\gamma}(\text{SM}) \simeq (0.44^{+0.24}_{-0.14})\%$ Hurth, Lunghi, Porod '03

$A_{CP}^{bs\gamma}(\text{exp.}) \simeq (0.4 \pm 3.6)\%$ HFAG

$$A_{CP}^{bs\gamma} \simeq \frac{\alpha_s}{|C_7|^2}\left(b_{27}\text{Im}(C_2C_7^*) + b_{87}\text{Im}(C_8C_7^*) + b_{28}\text{Im}(C_2C_8^*)\right)$$

- Sign of $A_{CP}^{bs\gamma}$ is correlated with sign of $S_{\phi K_S}$
- For $S_{\phi K_S} < S_{\phi K_S}^{SM}$, $A_{CP}^{bs\gamma}$ is unambiguously positive
- values typically in the range $1\% - 6\%$



ABP'08

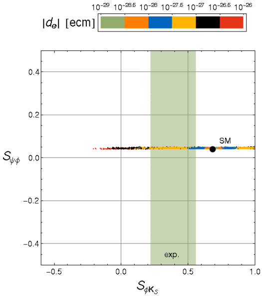
CP Violation in $\Delta F = 2$ transitions

1. Phases in the B_d and B_s mixing amplitudes

- Leading NP contributions to M_{12}^d and M_{12}^s turn out to be insensitive to the new phases of a flavor blind MSSM.

$$\text{Arg}(M_{12}^{d,s}) \simeq \text{Arg}(M_{12}^{d,s}(\text{SM}))$$

$\rightarrow S_{\psi K_S}$ and $S_{\psi\phi}$ are SM like



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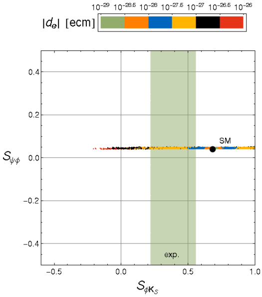
CP Violation in $\Delta F = 2$ transitions



ABP'08

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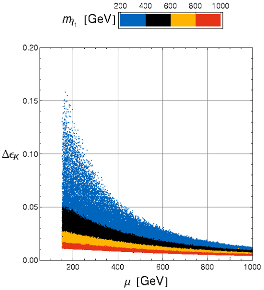


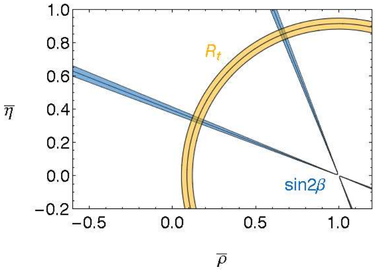
② CP violation in K mixing

- Also M_{12}^K has no sensitivity to the new phases
- Still, $\epsilon_K \propto \mathrm{Im}(M_{12}^K)$ can get a positive NP contribution up to 15%
- But only for a very light SUSY spectrum: $\mu, m_{\tilde{t}_1} \simeq 200\mathrm{GeV}$

- $S_{\psi K_S}$ and $\Delta M_d / \Delta M_s$ basically NP free
- UT can be constructed from the angle β and the side R_t

$$\sin 2\beta = S_{\psi K_S} = 0.680 \pm 0.025$$

$$R_t = \xi \frac{1}{\lambda} \sqrt{\frac{m_{B_s}}{m_{B_d}}} \sqrt{\frac{\Delta M_d}{\Delta M_s}} = 0.913 \pm 0.033$$



Implications for the Unitarity Triangle

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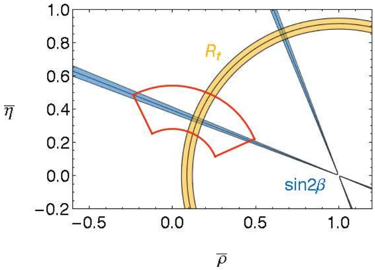
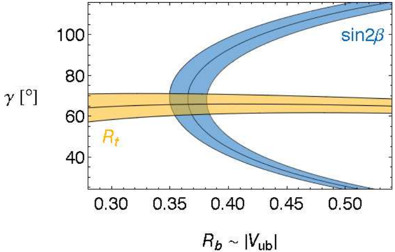
Predictions for $|V_{ub}|$ and the angle γ

$$|V_{ub}| = (3.5 \pm 0.2) \times 10^{-3}$$

$$\gamma = 63.5^\circ \pm 4.7^\circ$$





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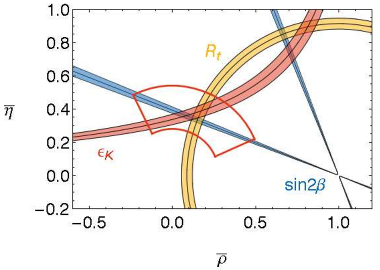

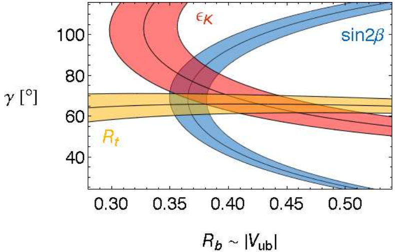

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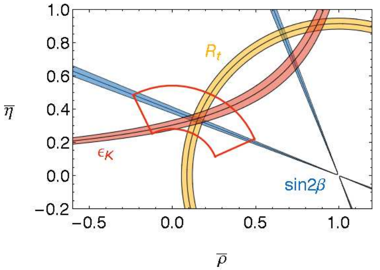
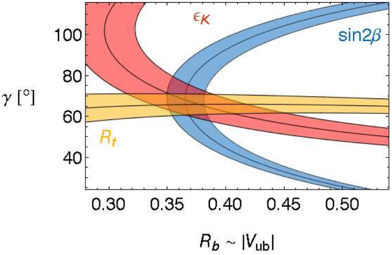
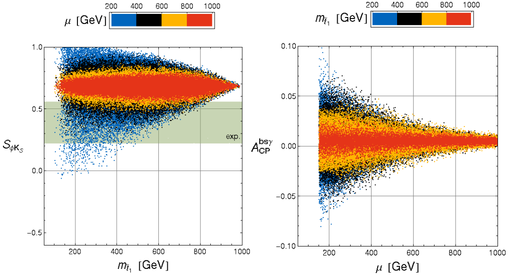
ϵ_K constraint ($B_K = 0.75 \pm 0.07$)
and with $+10\%$ NP corrections





Implications for direct searches of SUSY particles



ABP'08

- $S_{\phi K_S} \simeq 0.4$ implies $\mu \lesssim 600$GeV and $m_{\tilde{t}_1} \lesssim 700$GeV
- similarly, large non standard effects in $A_{CP}^{bs\gamma} \gtrsim 2\%$ imply $\mu \lesssim 600$GeV and $m_{\tilde{t}_1} \lesssim 800$GeV

Summary

In the flavor blind MSSM sizeable, correlated effects in $S_{\phi K_S}$ and $S_{\eta' K_S}$ are possible. Such effects imply:

- lower bounds on the electron and neutron EDMs at the level of $d_{e,n} \gtrsim 10^{-28} e\mathrm{cm}$
- a positive, sizeable direct CP asymmetry $A_{CP}^{bs\gamma} \simeq 1\% - 6\%$

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In the flavor blind MSSM sizeable, correlated effects in $S_{\phi K_S}$ and $S_{\eta' K_S}$ are possible. Such effects imply:

- lower bounds on the electron and neutron EDMs at the level of $d_{e,n} \gtrsim 10^{-28} ecm$
- a positive, sizeable direct CP asymmetry $A_{CP}^{bs\gamma} \simeq 1\% - 6\%$

In addition, within the framework of the FBMSSM, there are

- small effects in $S_{\psi\phi} \simeq 0.03 - 0.05$
- small effects in $S_{\psi K_S}$ and in $\Delta M_d / \Delta M_s$
  $\Rightarrow$ The Unitarity Triangle can be constructed from the side R_t and the angle β. Predictions: $|V_{ub}| = (3.5 \pm 0.2) \times 10^{-3}$ and $\gamma = 63.5^\circ \pm 4.7^\circ$.
- positive NP effects in ϵ_K up to 15%

Back Up

The Anomalous Magnetic Moment of the Muon

$a_\mu^{\text{exp.}} = 1165920.80(63) \times 10^{-9}$ Muon (g-2) collaboration

$a_\mu^{\text{SM}} = 1165917.85(61) \times 10^{-9}$ Miller et al. '07

$$\Delta a_\mu = a_\mu^{\text{exp.}} - a_\mu^{\text{SM}} \simeq (3 \pm 1) \times 10^{-9}$$

$\simeq 3\sigma$ discrepancy

A very rough formula for SUSY contributions to a_μ

$$a_\mu^{\text{SUSY}} \simeq 1.5 \left(\frac{\tan\beta}{10}\right) \left(\frac{300\text{GeV}}{m_{\tilde{\ell}}}\right)^2 \text{sign}(\text{Re}(\mu)) \times 10^{-9}$$

with common SUSY mass $m_{\tilde{\ell}}$

$S_{\phi K_S} \simeq 0.4$ naturally leads to $a_\mu^{\text{SUSY}} \simeq \text{few} \times 10^{-9}$