CP Violating Observables in a Flavor Blind MSSM

Wolfgang Altmannshofer

Physik Department
Technische Universität München

Fifth Workshop on Particle Physics and Cosmology
Warsaw
February 4 - 7, 2009

Outline

based on:

- WA, Andrzej Buras and Paride Paradisi
  Phys. Lett. B **669** (2008) 239
- WA, Patricia Ball, Aoife Bharucha, Andrzej Buras, David Straub and Michael Wick
  JHEP **0901** (2009) 019

---

1. Introduction: Hints for New Sources of CP Violation
2. A Flavor Blind MSSM
3. Phenomenology of CP Violation in the FBMSSM
4. Summary

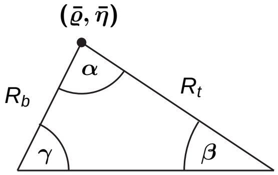
CP Violation in the SM

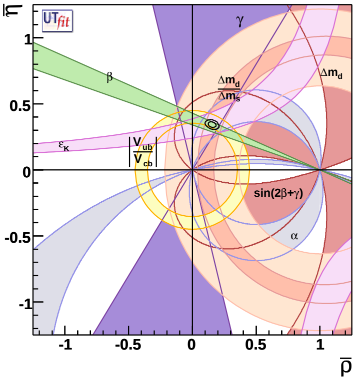
Apart from the QCD θ term,
the only source for CP violation in the SM
is the phase in the CKM matrix.

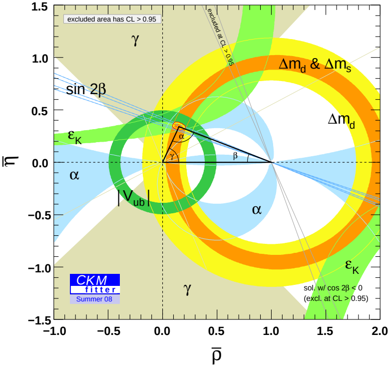
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\varrho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\varrho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

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

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



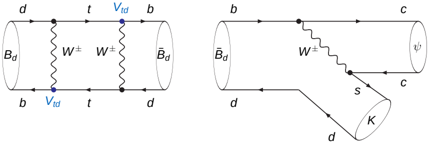


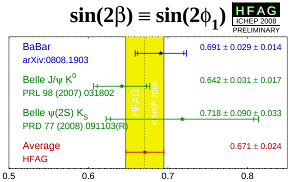


Impressive confirmation of the
CKM picture for CP violation

Hints for New Sources of CP violation?

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

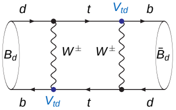


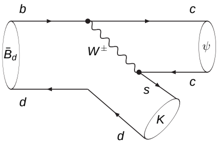


- Tree level decay $\longrightarrow$ sensitivity to the phase of the B_d mixing amplitude without NP in the decay amplitude
- in SM: $\mathrm{Arg}(M_{12}^d) = \mathrm{Arg}(V_{td}^2) = 2\beta$

$$\sin 2\beta \overset{\text{SM}}{=} S^{\text{exp.}}_{\psi K_S} = 0.671 \pm 0.024$$

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





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

$$\sin 2\beta \overset{\text{SM}}{=} S^{\text{exp.}}_{\psi K_S} = 0.671 \pm 0.024$$

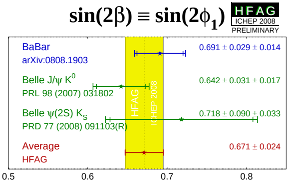
- In the SM also loop induced modes like $B \to \phi K_S$ and $B \to \eta' K_S$ give the same value

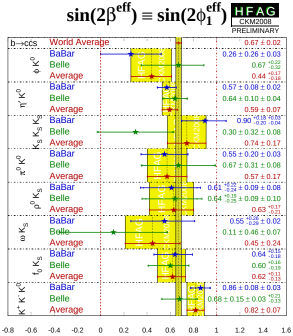
$$S^{SM}_{\phi K_S} = S^{SM}_{\eta' K_S} = S^{SM}_{\psi K_S} = \sin 2\beta$$

- But experimentally one has

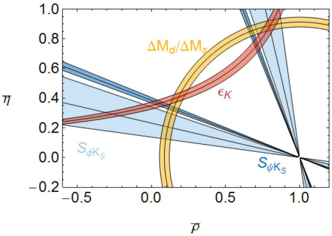
$$S^{\text{exp.}}_{\phi K_S} = 0.44 \pm 0.17\ , \quad S^{\text{exp.}}_{\eta' K_S} = 0.59 \pm 0.07$$

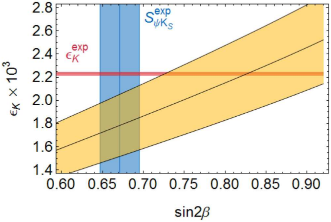
$\Rightarrow$ New Phases in decays?





Hints for New Sources of CP violation?





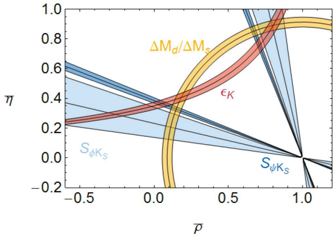
2 Tensions in the Unitarity Triangle

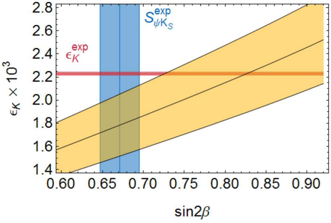
Lunghi, Soni '08; Buras, Guadagnoli '08, '09

- Construct the UT using only $S_{\psi K_S}$ and $\Delta M_d / \Delta M_s$
- $\sin 2\beta$ as determined from $B \to \psi K_S$ and R_t as determined from $\Delta M_d / \Delta M_s$ lead to a prediction for CP violation in the K system

$$\epsilon_K^{SM} = (1.78 \pm 0.25) \times 10^{-3} \quad \Leftrightarrow \quad \epsilon_K^{exp.} = (2.23 \pm 0.01) \times 10^{-3}$$

Hints for New Sources of CP violation?





2 Tensions in the Unitarity Triangle

Lunghi, Soni '08; Buras, Guadagnoli '08, '09

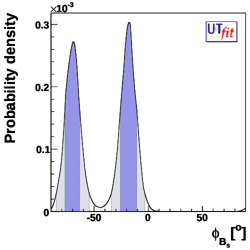
- Construct the UT using only $S_{\psi K_S}$ and $\Delta M_d / \Delta M_s$
- $\sin 2\beta$ as determined from $B \to \psi K_S$ and R_t as determined from $\Delta M_d / \Delta M_s$ lead to a prediction for CP violation in the K system

$$\epsilon_K^{SM} = (1.78 \pm 0.25) \times 10^{-3} \quad \Leftrightarrow \quad \epsilon_K^{exp.} = (2.23 \pm 0.01) \times 10^{-3}$$

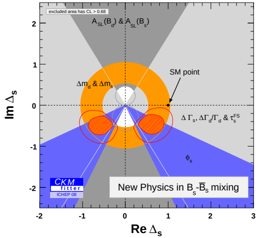
$\Rightarrow$ NP phase in B_d mixing?

$\Rightarrow$ Additional CP violation in K mixing?

Hints for New Sources of CP violation?

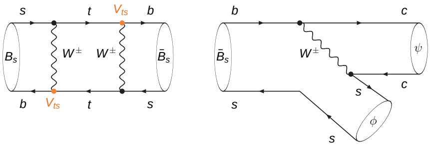


UTfit collaboration



CKM fitter collaboration

3. CP Asymmetry in $B_s \to \psi\phi$ and $\sin 2\beta_s$



- Tree level decay $\rightarrow$ sensitivity to the phase of the B_s mixing amplitude without NP in the decay amplitude
- in SM: $\mathrm{Arg}(M_{12}^s) = \mathrm{Arg}(V_{ts}^2) = 2\beta_s$ with $\beta_s \simeq 1^\circ$
- beyond the SM one has

$$S_{\psi\phi} = \sin 2(\beta_s + \Phi_{B_s}^{NP}) \ ,$$

- recent analyses seem to hint towards large NP effects

$$\Phi_{B_s}^{NP} = (19^\circ \pm 8^\circ) \cup (69^\circ \pm 7^\circ)$$

$\Rightarrow$ Large B_s mixing phase?

Going Beyond the Standard Model

Natural way to address these tensions/problems:

- go beyond the SM and introduce new CP violating phases

A Minimal Flavor Violating MSSM with additional CP violating phases

Baek, Ko '99

Bartl, Gajdosik, Lunghi, Masiero, Porod, Stremnitzer, Vives '01 (Flavor Blind MSSM)

Ellis, Lee, Pilaftsis '07 (MCPMFVMSSM)

WA, Buras, Paradisi '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 our setup

- 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

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

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b \bar{s}_L \sigma^{\mu\nu} F_{\mu\nu} b_R \quad , \quad \mathcal{O}_8 = \frac{g_s}{16\pi^2} m_b \bar{s}_L \sigma^{\mu\nu} G_{\mu\nu} b_R$$

The corresponding Wilson coefficients are mainly sensitive to one complex parameter combination

$$\mathcal{C}_{7,8} \propto \mu A_t$$

$\longrightarrow$ 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 $\tan\beta$

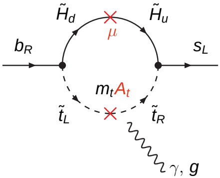
Most important constraints: EDMs and $b \to s\gamma$

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

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



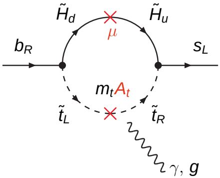
Most important constraints: EDMs and $b \to s\gamma$

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

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



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

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

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

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

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

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

$d_n^{\text{SM}} \simeq 10^{-32} e\text{cm}$

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

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

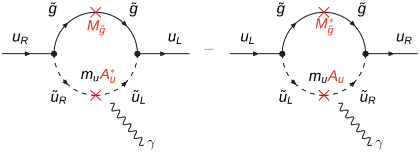
$d_e^{\text{exp.}} \lesssim 1.6 \times 10^{-27} e\text{cm}$

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

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

$d_n^{\text{SM}} \simeq 10^{-32} e\text{cm}$

- In the MSSM, EDMs can be induced already at the 1loop level
  $\longrightarrow$ typically tight constraints on CP violating phases
- Example: Gluino contribution to the up-quark EDM



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

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

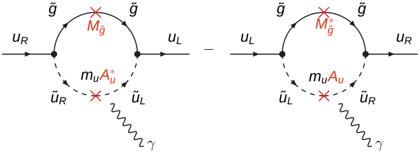
$d_e^{\text{exp.}} \lesssim 1.6 \times 10^{-27} e\text{cm}$

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

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

$d_n^{\text{SM}} \simeq 10^{-32} e\text{cm}$

- In the MSSM, EDMs can be induced already at the 1loop level
  $\longrightarrow$ typically tight constraints on CP violating phases
- Example: Gluino contribution to the up-quark EDM



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

Constraints can be avoided by e.g.

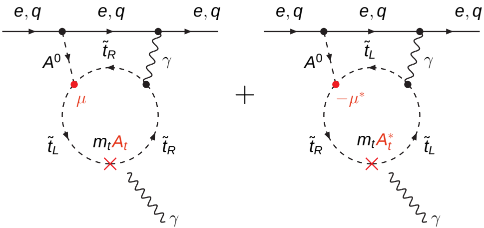
- hierarchical trilinear couplings $A_{u,c} \ll A_t,\, A_{d,s} \ll A_b$
- heavy 1st and 2nd generation of squarks

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

Chang, Keung, Pilaftsis ’98

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

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

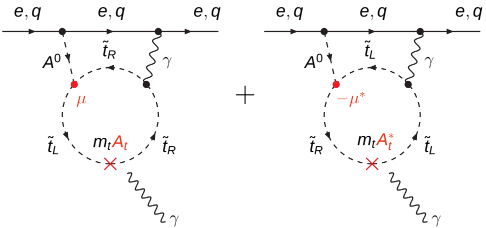


$$d_f \propto \mathrm{Im}(\mu A_t)$$

Chang, Keung, Pilaftsis '98

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

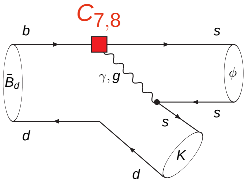
- sensitive to 3[rd] generation of squarks
- decouple with $1/\max(M^2_{A^0}, m^2_{\tilde{t}})$



$d_f \propto \mathrm{Im}(\mu A_t)$

$\longrightarrow$ Constraint on $\mathrm{Im}(\mu A_t)$

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

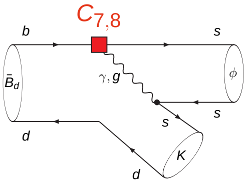


Time dependent CP Asymmetries in decays of neutral B mesons to final CP Eigenstates

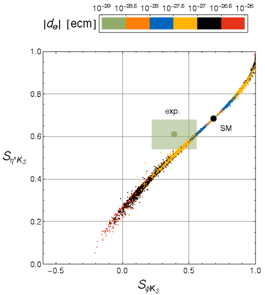
$$A_{CP}(t, \phi K_S) = \frac{\Gamma(B(t) \to \phi K_S) - \Gamma(\bar{B}(t) \to \phi K_S)}{\Gamma(B(t) \to \phi K_S) + \Gamma(\bar{B}(t) \to \phi K_S)}$$
$$= C_{\phi K_S} \cos(\Delta M_d t) - S_{\phi K_S} \sin(\Delta M_d t)$$

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

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

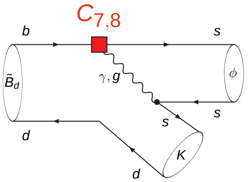


ABP'08

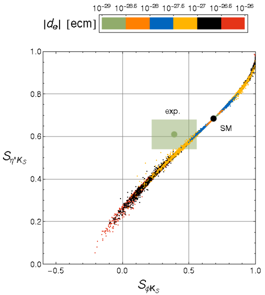
$$A_{CP}(t, \phi K_S) = \frac{\Gamma(B(t) \to \phi K_S) - \Gamma(\bar{B}(t) \to \phi K_S)}{\Gamma(B(t) \to \phi K_S) + \Gamma(\bar{B}(t) \to \phi K_S)}$$
$$= C_{\phi K_S} \cos(\Delta M_d t) - S_{\phi K_S} \sin(\Delta M_d t)$$

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

- 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



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

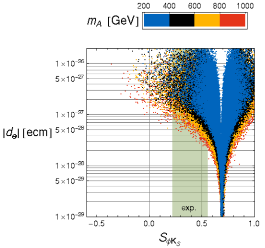


ABP'08

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

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

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



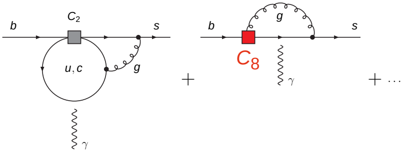
- sizeable, correlated effects in $S_{\phi K_S}$ and $S_{\eta' K_S}$
- larger effects in $S_{\phi K_S}$ as indicated by the data
- for $S_{\phi K_S} \simeq 0.4$, lower bounds on the electron and neutron EDMs:

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

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

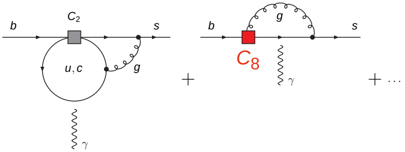
$A_{CP}^{bs\gamma}(\mathrm{SM}) \simeq (0.44^{+0.24}_{-0.14})\%$ Hurth, Lunghi, Porod '03

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

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

Soares '91; Kagan, Neubert '98

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



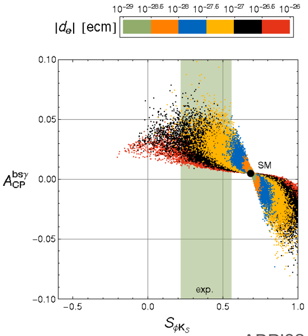
- arises first at order α_s
- doubly Cabibbo and GIM suppressed in the SM
- sizeable value would be clear signal for New Physics

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

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

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

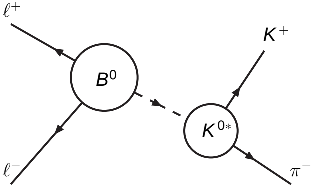
- Sign of $A_{CP}^{bs\gamma}$ is correlated with sign of $S_{\phi K_S}$
- For $S_{\phi K_S} < S_{\phi K_S}^{\mathrm{SM}}$, $A_{CP}^{bs\gamma}$ is unambiguously positive
- values typically in the range $1\% - 6\%$



ABP'08

The Decay $B^0 \to K^{0*}(\to K^+\pi^-)\ell^+\ell^-$ ...

Bobeth, Hiller, Piranishvili '08
Egede, Hurth, Matias, Ramon, Reece '08
WA, Ball, Bahrucha, Buras, Straub, Wick '09



$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi} = \frac{9}{32\pi} I(q^2, \theta_l, \theta_{K^*}, \phi)$$

$$\begin{aligned} I(q^2, \theta_l, \theta_{K^*}, \phi) = \\ &= I_1^s \sin^2\theta_{K^*} + I_1^c \cos^2\theta_{K^*} + (I_2^s \sin^2\theta_{K^*} + I_2^c \cos^2\theta_{K^*}) \cos 2\theta_l \\ &+ I_3 \sin^2\theta_{K^*} \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_{K^*} \sin 2\theta_l \cos\phi \\ &+ I_5 \sin 2\theta_{K^*} \sin\theta_l \cos\phi \\ &+ (I_6^s \sin^2\theta_{K^*} + I_6^c \cos^2\theta_{K^*}) \cos\theta_l + I_7 \sin 2\theta_{K^*} \sin\theta_l \sin\phi \\ &+ I_8 \sin 2\theta_{K^*} \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_{K^*} \sin^2\theta_l \sin 2\phi \end{aligned}$$

Full angular reconstruction possible at LHCb

7200 events with $2fb^{-1}$ ($\approx$ 1 year of running)

Consider both $B^0 \to K^{0*}(\to K^+\pi^-)\ell^+\ell^-$ and the CP conjugate mode $\bar{B}^0 \to \bar{K}^{0*}(\to K^-\pi^+)\ell^+\ell^-$

allows to construct up to 24 observables that can be measured through the angular analysis

CP averaged angular coefficients

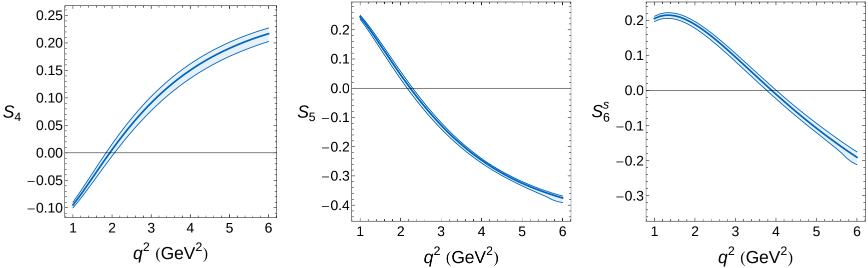
$$S_i = (I_i + \bar{I}_i) \bigg/ \frac{d(\Gamma + \bar{\Gamma})}{dq^2}$$

CP asymmetries

$$A_i = (I_i - \bar{I}_i) \bigg/ \frac{d(\Gamma + \bar{\Gamma})}{dq^2}$$

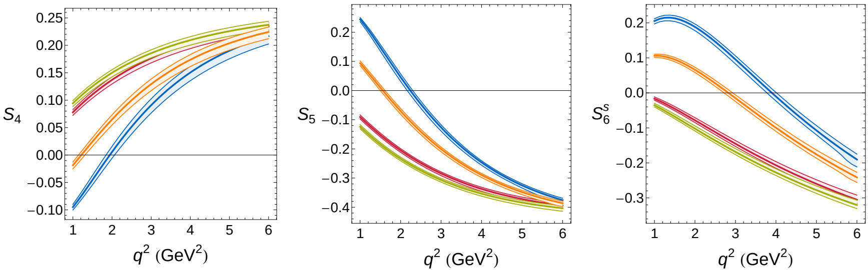
most interesting ones in the context of the FBMSSM are S_4, S_5, S_6^s, A_7 and A_8

NP Effects in the Angular Observables



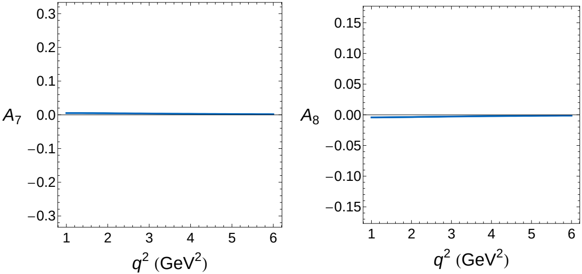
- S_6^s is basically the well known forward-backward asymmetry in $B \to K^* \ell^+ \ell^-$
- The CP averaged angular observables S_4, S_5 and S_6^s have zeros in their q^2 distributions

NP Effects in the Angular Observables



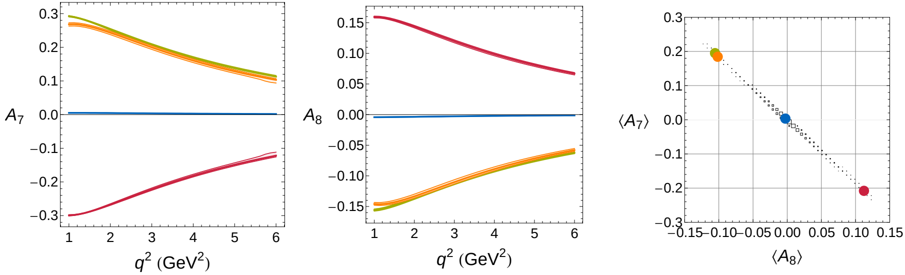
- S_6^s is basically the well known forward-backward asymmetry in $B \to K^* \ell^+ \ell^-$
- The CP averaged angular observables S_4, S_5 and S_6^s have zeros in their q^2 distributions
- The large complex NP contributions to $\mathcal{C}_7$ in the FBMSSM lead to significant shifts in the zeros of S_4, S_5 and S_6^s towards lower values

NP Effects in the Angular Observables



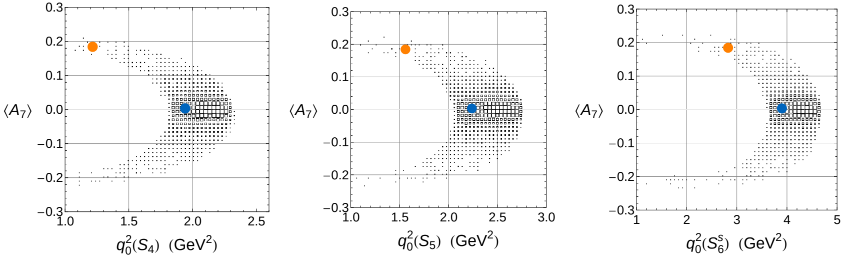
- The CP asymmetries A_7 and A_8 are negligible small in the SM

NP Effects in the Angular Observables



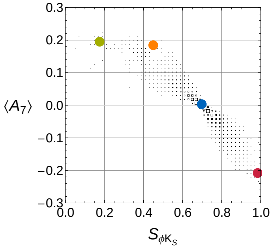
- The CP asymmetries A_7 and A_8 are negligible small in the SM
- In the FBMSSM huge effects are possible and they are highly correlated
- Deviations from the correlation point clearly towards sizeable complex NP contributions to other operators, e.g. $\mathcal{C}_7'$

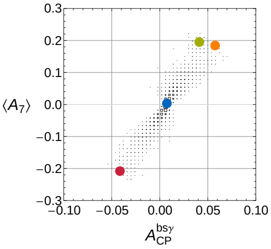
Correlations among Angular Observables

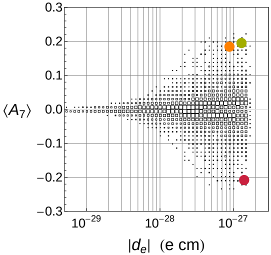


- There are also strong correlations between the integrated CP asymmetries $\langle A_7 \rangle$ and $\langle A_8 \rangle$ and the zeros of S_4, S_5 and S_6^s
- Large shifts in the zeros unambiguously lead to large effects in the CP asymmetries

Correlations with Other CP Violating Observables







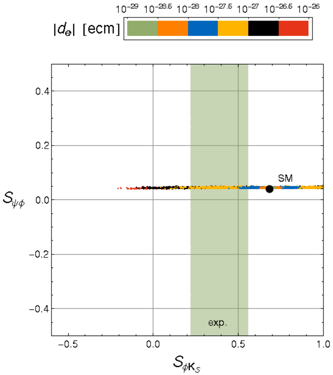
- $\langle A_7 \rangle$ and $\langle A_8 \rangle$ are also correlated with $S_{\phi K_S}$ and $S_{\eta' K_S}$
- $S_{\phi K_S} \simeq 0.4$ implies positve $\langle A_7 \rangle \simeq 0.05 \div 0.2$ and negative $\langle A_8 \rangle \simeq -0.11 \div -0.03$
- Finally, $\langle A_7 \rangle$ and $\langle A_8 \rangle$ are also correlated with the CP asymmetry in $b \to s\gamma$ and the EDMs

1. Phases in the B_d and B_s mixing amplitudes

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

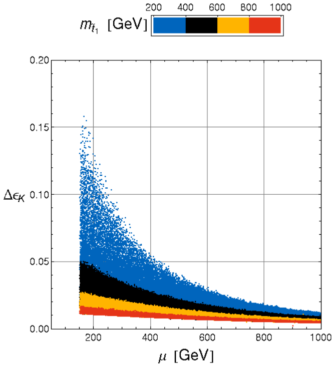
$$\mathrm{Arg}(M_{12}^{d,s}) \simeq \mathrm{Arg}(M_{12}^{d,s}(\mathrm{SM}))$$

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



ABP'08

CP Violation in $\Delta F = 2$ Transitions



ABP'08

② CP violation in K mixing

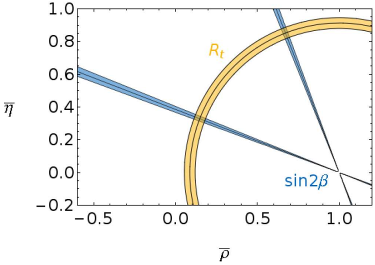
- Also M_{12}^K has no sensitivity to the new flavor blind phases
- Still, $\epsilon_K \propto \mathrm{Im}(M_{12}^K)$ can get a positive NP contribution up to 15%
- But only for a very light SUSY spectrum: $\mu, m_{\tilde{t}_1} \simeq 200\mathrm{GeV}$

Implications for the Unitarity Triangle

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

$$\sin 2\beta = S_{\psi K_S} = 0.671 \pm 0.024$$

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



Implications for the Unitarity Triangle

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

$$\sin 2\beta = S_{\psi K_S} = 0.671 \pm 0.024$$

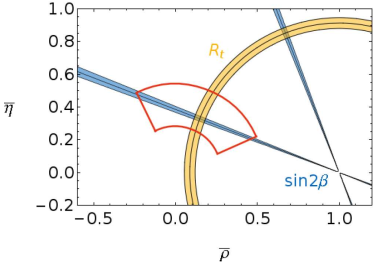
$$R_t = \xi \frac{1}{\lambda} \sqrt{\frac{m_{B_s}}{m_{B_d}}} \sqrt{\frac{\Delta M_d}{\Delta M_s}} = 0.913 \pm 0.033$$

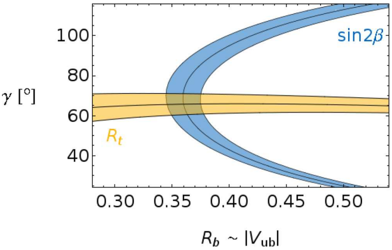
Predictions for $|V_{ub}|$ and the angle γ

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

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

$\rightarrow$ can be tested at a SuperB Factory





Implications for the Unitarity Triangle

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

$$\sin 2\beta = S_{\psi K_S} = 0.671 \pm 0.024$$

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

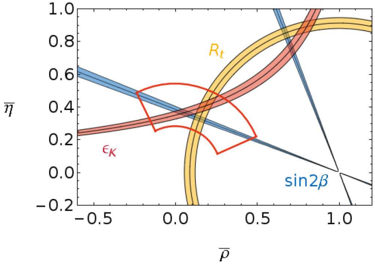
Predictions for $|V_{ub}|$ and the angle γ

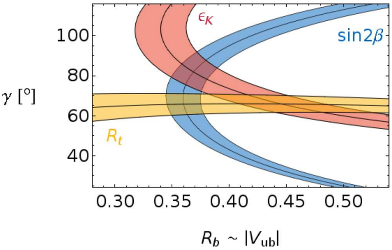
$$|V_{ub}| = (3.5 \pm 0.2) \times 10^{-3}$$

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

$\rightarrow$ can be tested at a SuperB Factory

ϵ_K constraint ($B_K = 0.72 \pm 0.05$)





Implications for the Unitarity Triangle

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

$$\sin 2\beta = S_{\psi K_S} = 0.671 \pm 0.024$$

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

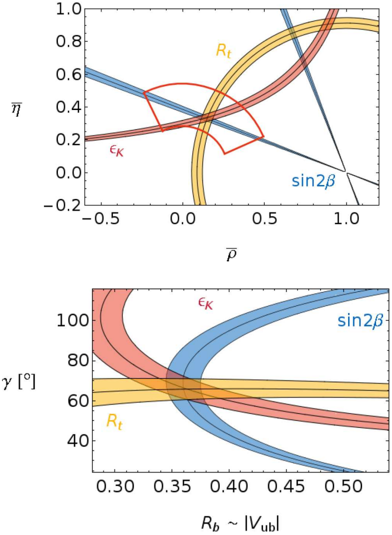
Predictions for $|V_{ub}|$ and the angle γ

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

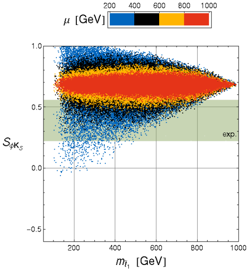
$$\gamma = 63.5^\circ \pm 4.7^\circ$$

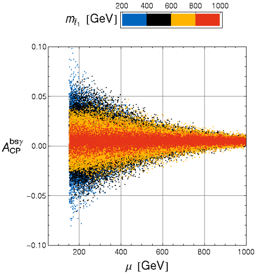
$\rightarrow$ can be tested at a SuperB Factory

ϵ_K constraint ($B_K = 0.72 \pm 0.05$)
and with $+15\%$ 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 $d_{e,n} \gtrsim 10^{-28} ecm$
- a positive, sizeable direct CP asymmetry $A_{CP}^{bs\gamma} \simeq 1\% - 6\%$

Summary

The decay $B \to K^* \ell^+ \ell^-$ offers a multitude of observables sensitive to new CP violating phases. In the FBMSSM we find:

- The zeros of the CP averaged coefficients S_4, S_5 and S_6^s are shifted towards lower values
- Sizeable effects in the CP asymmetries A_7 and A_8
- These effects are highly correlated among themselves and also with $S_{\phi K_S}$, $A_{CP}^{bs\gamma}$ and $d_{e,n}$
- The definite pattern of effects allows a clear distinction from scenarios where Wilson coefficients other than $\mathcal{C}_7$ play an important role

Summary

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

$a_\mu^{\text{exp.}} = 1165\mathbf{920.80}(63) \times 10^{-9}$ Muon (g-2) collaboration

$a_\mu^{\text{SM}} = 1165\mathbf{917.85}(61) \times 10^{-9}$ 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 $a_\mu^{\text{SUSY}} \simeq$ few $\times 10^{-9}$