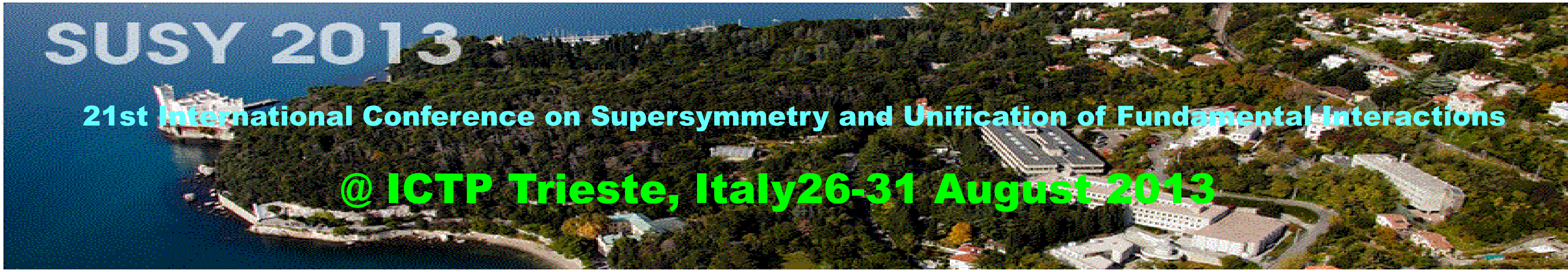


Probing Supersymmetry in B meson decays facing the recent LHC data

26 August 2013

Kei Yamamoto Niigata University in JAPAN

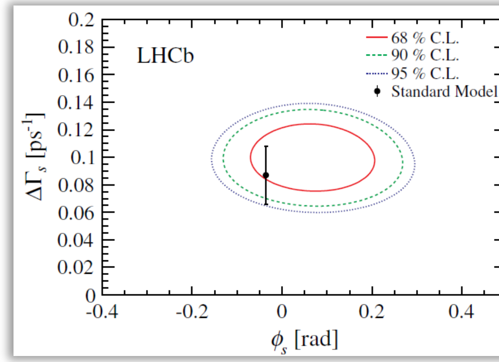
Collaborated with Y.Shimizu(Max Planck Institute), M.Tanimoto (Niigata Univ.)

Y.Shimizu, M.Tanimoto, K.Y. [arXiv:1307.0374]

Introduction

The LHCb collaboration has reported new data of the CP violation of Bs meson.

Time dependent CP asymmetry in $B_s^0 \to J/\psi K^+ K^-$ **[LHCb, Phys. Rev. D 87, 112010(2013)]**



$$\phi_s(\mathrm{Exp}) = 0.07 \pm 0.09 \pm 0.01$$

$$\phi_s(\mathrm{SM}) = -0.0363 \pm 0.0017$$ [The CKMfitter,2011]

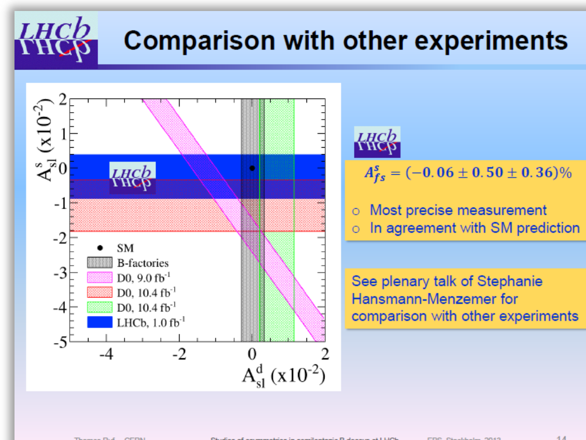
$$\mathrm{Asymmetry} = \sin\phi_s$$

Time dependent CP asymmetry in $B_s \to \phi\phi$ **[LHCb, Phys.Rev.Lett.110, 241802 (2013)]**

$$\phi_s^{\phi\phi}(\mathrm{Exp}) = [-2.46, -0.78]\mathrm{rad}\ \ (68\%\mathrm{C.L.})$$

$\phi_s^{\phi\phi}(\mathrm{SM})$ O(λ^4)

Semi-leptonic asymmetry a_{sl}^s **[EPS conference 2013]**



$$a_{sl}^s(\mathrm{Exp}) = (-0.06 \pm 0.50 \pm 0.36)\%$$

$$a_{sl}^s(\mathrm{SM}) = (0.0019 \pm 0.0003)\%$$ [A.Lenz,2012]

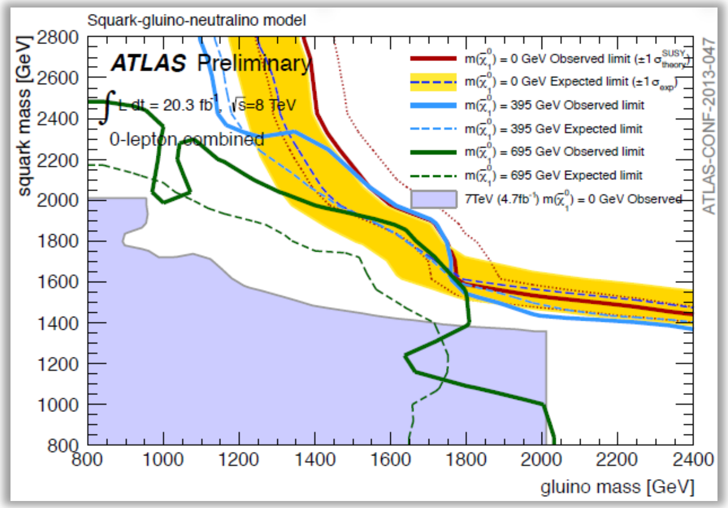
Introduction

Searching for SUSY particle at LHC

The SUSY signals have not been observed yet.
The lower bounds for the susy-particle masses have pushed up to TeV scale.

95% CL exclusions for (best) massless LSP scenarios:

$m(\tilde{g}) < 1300$ GeV
$m(\tilde{q}) < 1400$ GeV
$m(\tilde{b}) < 650$ GeV
$m(\tilde{t}) < 680$ GeV
$m(\tilde{\ell}_L) < 300$ GeV



[Lepton-Photon sympo. 2013 06]

Indirect search for SUSY is important.

B physics can become the indirect search for SUSY.
We discuss the sensitivity of the SUSY contribution to B decays.

Setup

Natural SUSY scenario [A.G.Cohen, D.B.Kaplan and A.E.Nelson, PLB 388 (1996) 588]

The first and second family squarks are very heavy, at O(10)TeV, on the other hand, the third family squark masses are at O(1)TeV.

$$m_{\tilde{q}_{1,2}} = \mathcal{O}(10)\ \mathrm{TeV} \qquad m_{\tilde{b}_1} = 1\ \mathrm{TeV}, m_{\tilde{b}_2} = 1.1\ \mathrm{TeV} \qquad m_{\tilde{g}} = 2\ \mathrm{TeV}$$

The gluino-squark-quark interaction

$$\mathcal{L}_{\mathrm{int}}(\tilde{g}q\tilde{q}) = -i\sqrt{2}g_s \sum_{\{q\}} \widetilde{q}_i^{*}(T^a)\overline{\widetilde{G}^a}\left[(\Gamma^{(q)}_{GL})_{ij}\boldsymbol{L} + (\Gamma^{(q)}_{GR})_{ij}\boldsymbol{R}\right] q_j + \mathrm{h.c.}$$

Mixing matrix We work in the basis of mass eigenstate.

$$\Gamma^{(d)}_{GL} = \begin{array}{cc} \begin{pmatrix} 1 & 0 & \delta^{dL}_{13} c_\theta & 0 & 0 & -\delta^{dL}_{13} s_\theta e^{i\phi} \\ 0 & 1 & \delta^{dL}_{23} c_\theta & 0 & 0 & -\delta^{dL}_{23} s_\theta e^{i\phi} \\ -\delta^{dL\,*}_{13} & -\delta^{dL\,*}_{23} & c_\theta & 0 & 0 & -s_\theta e^{i\phi} \end{pmatrix} & \begin{array}{c} d_L \\ s_L \\ b_L \end{array} \end{array}$$

$$\Gamma^{(d)}_{GR} = \begin{array}{cc} \begin{pmatrix} 0 & 0 & \delta^{dR}_{13} s_\theta e^{-i\phi} & 1 & 0 & \delta^{dR}_{13} c_\theta \\ 0 & 0 & \delta^{dR}_{23} s_\theta e^{-i\phi} & 0 & 1 & \delta^{dR}_{23} c_\theta \\ 0 & 0 & s_\theta e^{-i\phi} & -\delta^{dR*}_{13} & -\delta^{dR*}_{23} & c_\theta \end{pmatrix} & \begin{array}{c} d_R \\ s_R \\ b_R \end{array} \\ \begin{array}{cccccc} \tilde{d}_1 & \tilde{s}_1 & \tilde{b}_1 & \tilde{d}_2 & \tilde{s}_2 & \tilde{b}_2 \end{array} & \end{array}$$

We assume the mixing parameters $\delta^{\mathrm{dL}}_{13}, \delta^{\mathrm{dL}}_{23}, \delta^{\mathrm{dR}}_{13}, \delta^{\mathrm{dR}}_{23}$ as $|\delta^{\mathrm{dL}}_{13}| = |\delta^{\mathrm{dR}}_{13}|, |\delta^{\mathrm{dL}}_{23}| = |\delta^{\mathrm{dR}}_{23}|$.

We assume the mixing angle $\theta = 10^\circ \sim 35^\circ$.

(Mixing angle between the left-handed sbottom and the right-handed one.)

Targets

	K meson	B meson	Bs meson
ΔF=2 : Mixing	$\lvert\epsilon_K\rvert$	ΔM_d	ΔM_s
ΔF=1 : Time dependent CP asymmetry		$S_{J/\psi K_S}$	$S_{J/\psi\phi}$
		$S_{\phi K_S}, S_{\eta' K^0}$	$S_{\phi\phi,\eta'\phi}$
		$S_{K^0 \bar{K}^0}$	
: Branching ratio		$\mathrm{BR}(b \to s\gamma)$	$\mathrm{BR}(b \to s\gamma)$
: CP asymmetry in the semileptonic decay		a_{sl}^d	a_{sl}^s

ΔF=0 : Chromo EDM of strange quark

$$\lvert d_s^C\rvert$$

Targets

	K meson	B meson	Bs meson
ΔF=2 : Mixing	$\lvert\epsilon_K\rvert$	ΔM_d	ΔM_s
ΔF=1 : Time dependent CP asymmetry		$S_{J/\psi K_S}$	$S_{J/\psi\phi}$
		$S_{\phi K_S}, S_{\eta' K^0}$	$S_{\phi\phi,\eta'\phi}$
		$S_{K^0 \bar{K}^0}$	
: Branching ratio		$\mathrm{BR}(b \to s\gamma)$	
: CP asymmetry in the semileptonic decay		a_{sl}^d	a_{sl}^s
ΔF=0 : Chromo EDM of strange quark	$\lvert d_s^C\rvert$		

Step1

Constraints for SUSY mixing parameters

$\delta_{13}^{\mathrm{dL}}, \delta_{23}^{\mathrm{dL}}, \delta_{13}^{\mathrm{dR}}, \delta_{23}^{\mathrm{dR}}$

Targets

	K meson	B meson	Bs meson
ΔF=2 : Mixing	$\lvert\epsilon_K\rvert$	ΔM_d	ΔM_s
ΔF=1 : Time dependent CP asymmetry		$S_{J/\psi K_S}$	$S_{J/\psi\phi}$
		$S_{\phi K_S}, S_{\eta' K^0}$ $S_{K^0 \bar{K}^0}$	$S_{\phi\phi,\eta'\phi}$
: Branching ratio		$\mathrm{BR}(b \to s\gamma)$	
: CP asymmetry in the semileptonic decay		a^d_{sl}	a^s_{sl}
ΔF=0 : Chromo EDM of strange quark	$\lvert d^C_s\rvert$		

Step1

Constraints for SUSY mixing parameters

$\delta^{\rm dL}_{13}, \delta^{\rm dL}_{23}, \delta^{\rm dR}_{13}, \delta^{\rm dR}_{23}$

Step2

Prediction

Targets

K meson | B meson | Bs meson

ΔF=2 : Mixing

$|\epsilon_K|$ ΔM_d ΔM_s

ΔF=1 : Time dependent CP asymmetry

$S_{J/\psi K_S}$ $S_{J/\psi\phi}$

$S_{\phi K_S}, S_{\eta' K^0}$ $S_{\phi\phi,\eta'\phi}$

$S_{K^0 K^0}$

: Branching ratio

$\mathrm{BR}(b \to s\gamma)$

: CP asymmetry in the semileptonic decay

a^d_{sl} a^s_{sl}

ΔF=0 : Chromo EDM of strange quark

$|d^C_s|$

Step1

Constraints for SUSY mixing parameters

$\delta^{\mathrm{dL}}_{13}, \delta^{\mathrm{dL}}_{23}, \delta^{\mathrm{dR}}_{13}, \delta^{\mathrm{dR}}_{23}$

Prediction

Targets

	K meson	B meson	Bs meson
ΔF=2 : Mixing	$\lvert\epsilon_K\rvert$	ΔM_d	ΔM_s
ΔF=1 : Time dependent CP asymmetry		$S_{J/\psi K_S}$	$S_{J/\psi\phi}$
		$S_{\phi K_S}, S_{\eta' K^0}$, $S_{K^0 K^0}$	$S_{\phi\phi,\eta'\phi}$
: Branching ratio		$\mathrm{BR}(b \to s\gamma)$	
: CP asymmetry in the semileptonic decay		a_{sl}^d	a_{sl}^s
ΔF=0 : Chromo EDM of strange quark	$\lvert d_s^C\rvert$		

$S_{J/\psi K_S}$-$\lvert\epsilon_K\rvert$ tension

Step1

Constraints for SUSY mixing parameters
$\delta_{13}^{\mathrm{dL}}, \delta_{23}^{\mathrm{dL}}, \delta_{13}^{\mathrm{dR}}, \delta_{23}^{\mathrm{dR}}$

Prediction

$S_{J/\psi K_S}$-$|\varepsilon_K|$ tension

[Andrzej J. Buras and Diego Guadagnoli ,2008]
[Andrzej J. Buras ,2011]

$|\epsilon_K|$ is given in terms of $\sin(2\beta)$ because there is only one CP violating phase in the SM.

SM $|\varepsilon_K| \propto \hat{B}_K\, |V_{cb}|^4 \sin(2\beta_{SM})$ $S_{J/\psi K_S} = \sin(2\beta_{exp}) = \sin(2\beta_{SM})$

B_K parameter

$$B_K = \frac{\langle \bar{K}^0 | O^{\Delta S=2} | K^0 \rangle}{\frac{8}{3} \langle \bar{K}^0 | A_\mu | 0 \rangle \langle 0 | A^\mu | K^0 \rangle} \qquad \hat{B}_K \equiv [\alpha_s(\mu)]^{-2/9} \left[1 + \frac{\alpha_s(\mu)}{4\pi} J_3 \right] B_K(\mu)$$

Recent lattice work [C.Aubin, et all ,2009]

$$\hat{B}_K = 0.73 \pm 0.03$$

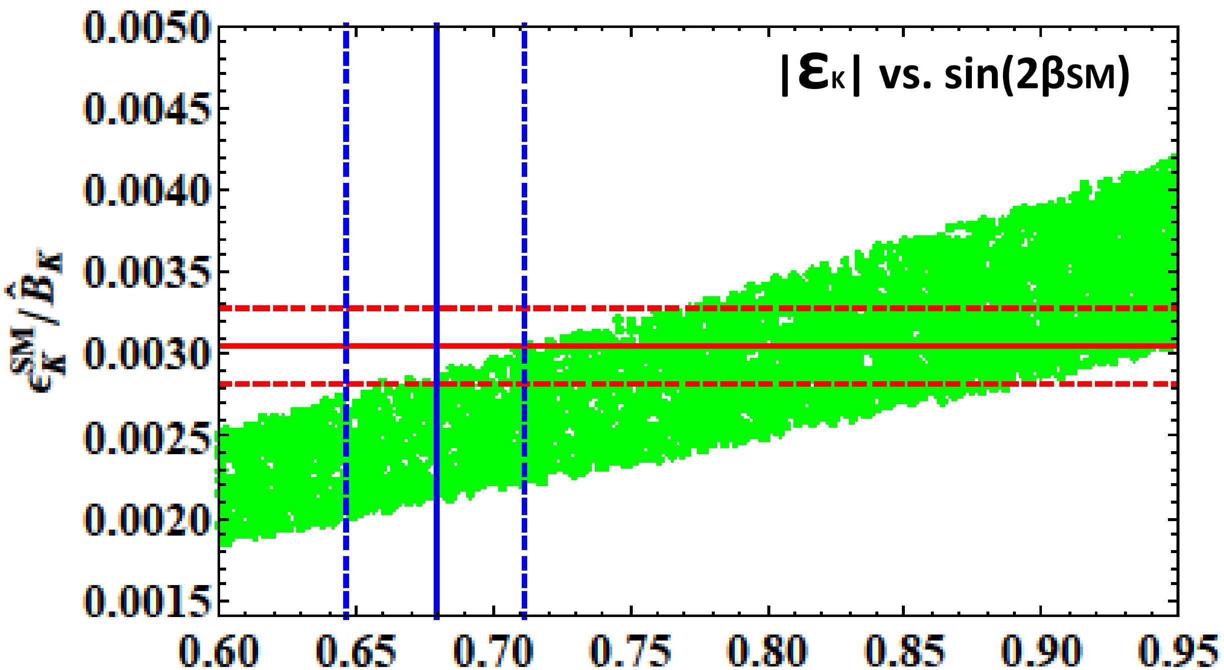
$S_{J/\psi K_S}$-$|\varepsilon_K|$ tension

[Andrzej J. Buras and Diego Guadagnoli ,2008]
[Andrzej J. Buras ,2011]

$|\epsilon_K|$ is given in terms of $\sin(2\beta)$ because there is only one CP violating phase in the SM.

SM $|\varepsilon_K| \propto \hat{B}_K |V_{cb}|^4 \sin(2\beta_{SM})$ $S_{J/\psi K_S} = \sin(2\beta_{exp}) = \sin(2\beta_{SM})$

$|\varepsilon_K|$



$|\varepsilon_K|^{exp}$ 90%C.L.

$S_{J/\psi K_S} = 0.679 \pm 0.02$ 90%C.L.

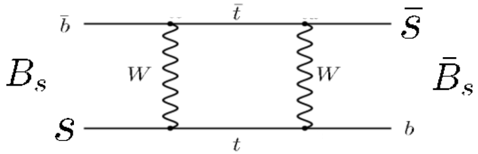
$\sin(2\beta_{SM})$

It is noticed that the consistency between the SM prediction and the experimental data in $\sin(2\beta)$ and $|\epsilon_K^{SM}|/\hat{B}_K$ is marginal.
We will show that this tension is understood by taking account of the SUSY box diagram through the gluino-sbottom-quark interaction.

Constraints

ΔF=2 process : K-$\overline{\text{K}}$, B-$\overline{\text{B}}$, Bs-$\overline{\text{B}}$s mixing $|\epsilon_K|$ ΔM_d ΔM_s

Standard model



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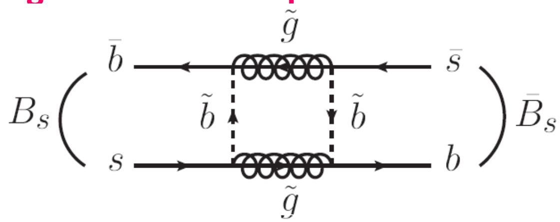
The gluino-sbottom-quark interaction



constrains

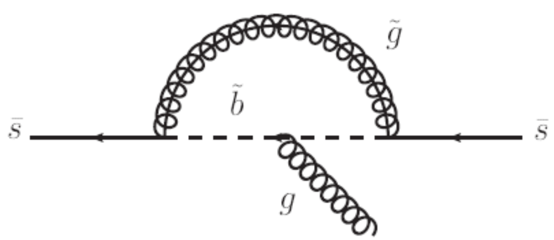
$|\epsilon_K| \longrightarrow \delta^d_{13} \times \delta^d_{23}$

$\Delta M_d \longrightarrow \delta^d_{13}$

$\Delta M_s \longrightarrow \delta^d_{23}$

ΔF=0 process : Chromo EDM of strange quark $|d^C_s|$

The gluino-sbottom-quark interaction



[K.Fuyuto, J.Hisano and N.Nagata, Phys.Rev.D 87 (2013)]

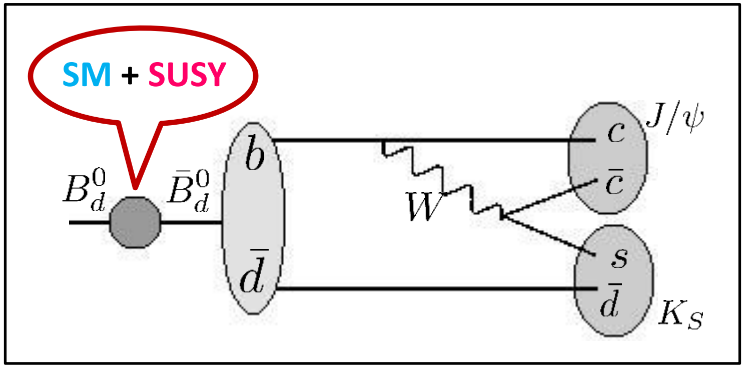
$$e|d^C_s| < 0.5 \times 10^{-25}\mathrm{ecm}$$

constrains

$|d^C_s| \longrightarrow \delta^d_{23}$

Constraints

ΔF=1 process **: Time dependent CP asymmetry** $S_{J/\psi K_S}$ $S_{J/\psi\phi}$



The dispersive part of mixing

$$M_{12}^q = M_{12}^{q,\mathrm{SM}} + M_{12}^{q,\mathrm{SUSY}}$$
$$= M_{12}^{q,\mathrm{SM}}(1 + h_q e^{2i\sigma_q})$$
$$(q = d, s)$$

$$S_f = \frac{2\mathrm{Im}(\lambda_f)}{1 + |\lambda_f|^2} \quad \left(\lambda = \frac{q}{p} \frac{\bar{A}^{SM} + \bar{A}^{SUSY}}{A^{SM} + A^{SUSY}} \right)$$

$$\frac{q}{p} \simeq \sqrt{\frac{M_{12}^*}{M_{12}}} = \sqrt{\frac{M_{12}^{SM*}}{M_{12}^{SM}}} \sqrt{\frac{1 + h_d e^{-2i\sigma_d}}{1 + h_d e^{2i\sigma_d}}}$$

SM → **SM + SUSY**

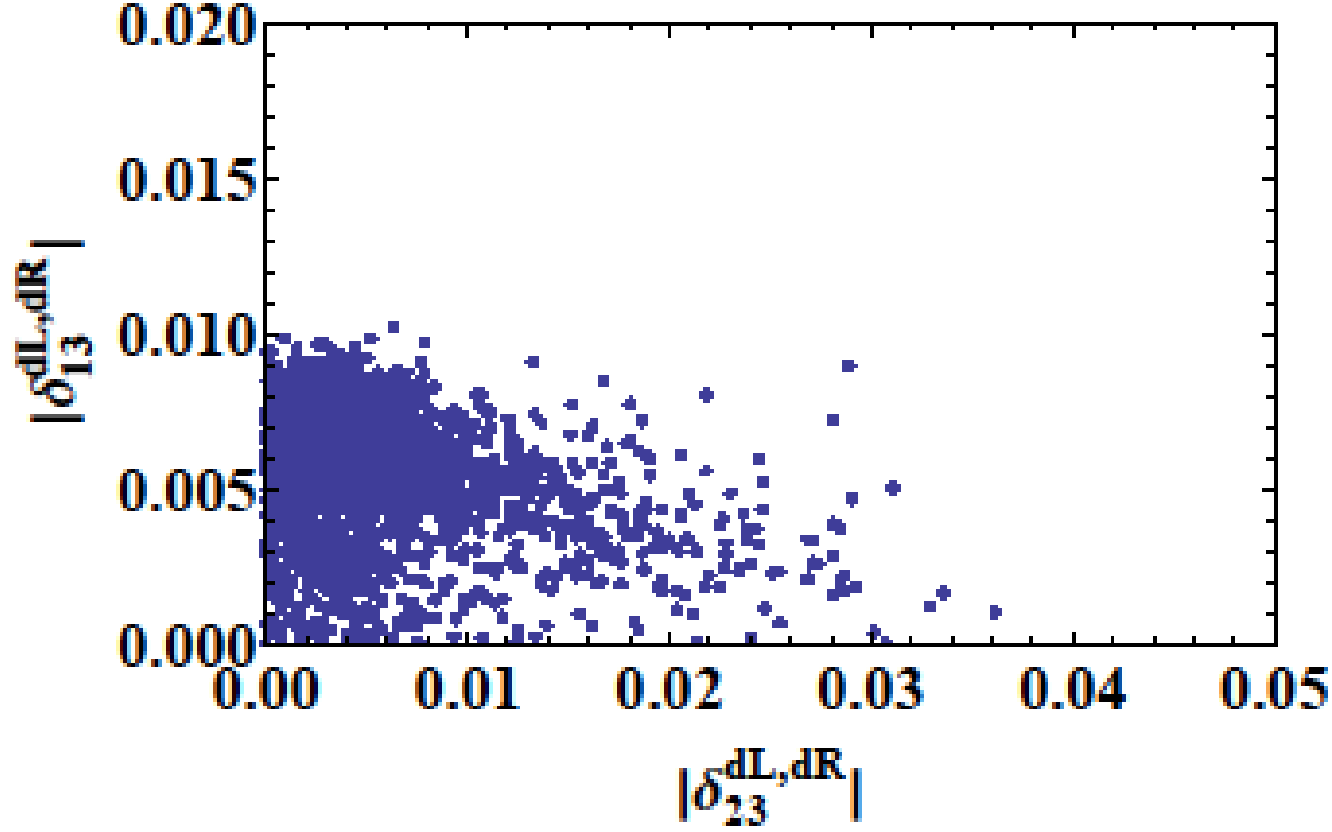
$$S_{J/\psi K_S} = \sin(2\beta_{\mathrm{SM}}) \rightarrow \sin(2\beta_{\mathrm{SM}} + \mathrm{Arg}(1 + h_d e^{2i\sigma_d}))$$
$$S_{J/\psi\phi} = \sin(-2\beta_{s\mathrm{SM}}) \rightarrow \sin(-2\beta_{s\mathrm{SM}} + \mathrm{Arg}(1 + h_s e^{2i\sigma_s}))$$

constrains

$$S_{J/\psi K_S} \longrightarrow \delta_{13}^d$$
$$S_{J/\psi\phi} \longrightarrow \delta_{23}^d$$

Numerical results

Allowed region of |δ13|, |δ23|

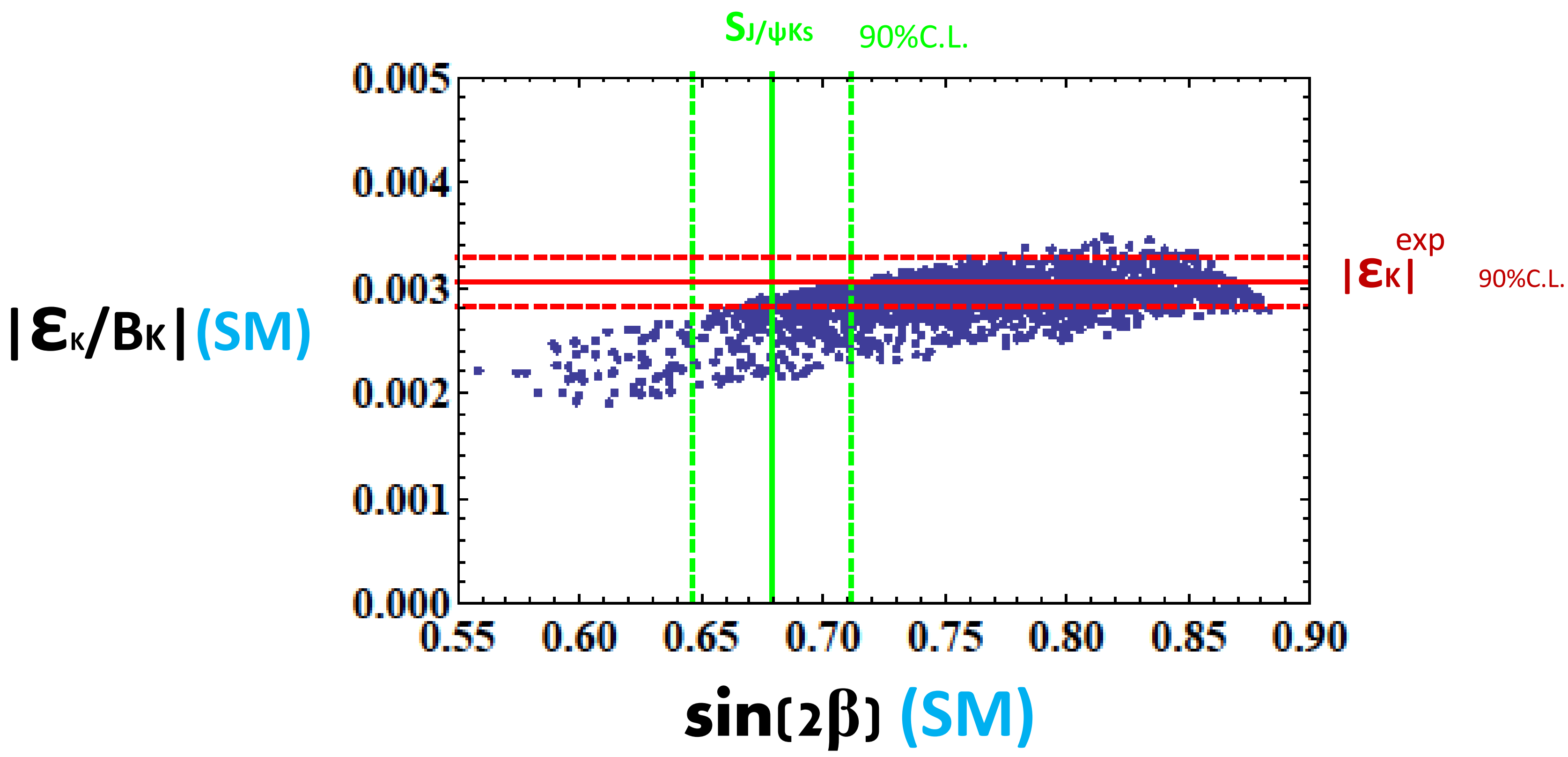


$|\delta_{13}^{dL(dR)}| = 0 \sim 0.01 \qquad |\delta_{23}^{dL(dR)}| = 0 \sim 0.04$

@ $m_{\tilde{b}_1} = 1\ \mathrm{TeV}, m_{\tilde{b}_2} = 1.1\ \mathrm{TeV} \quad m_{\tilde{g}} = 2\ \mathrm{TeV} \quad \theta = 10^\circ \sim 35^\circ$

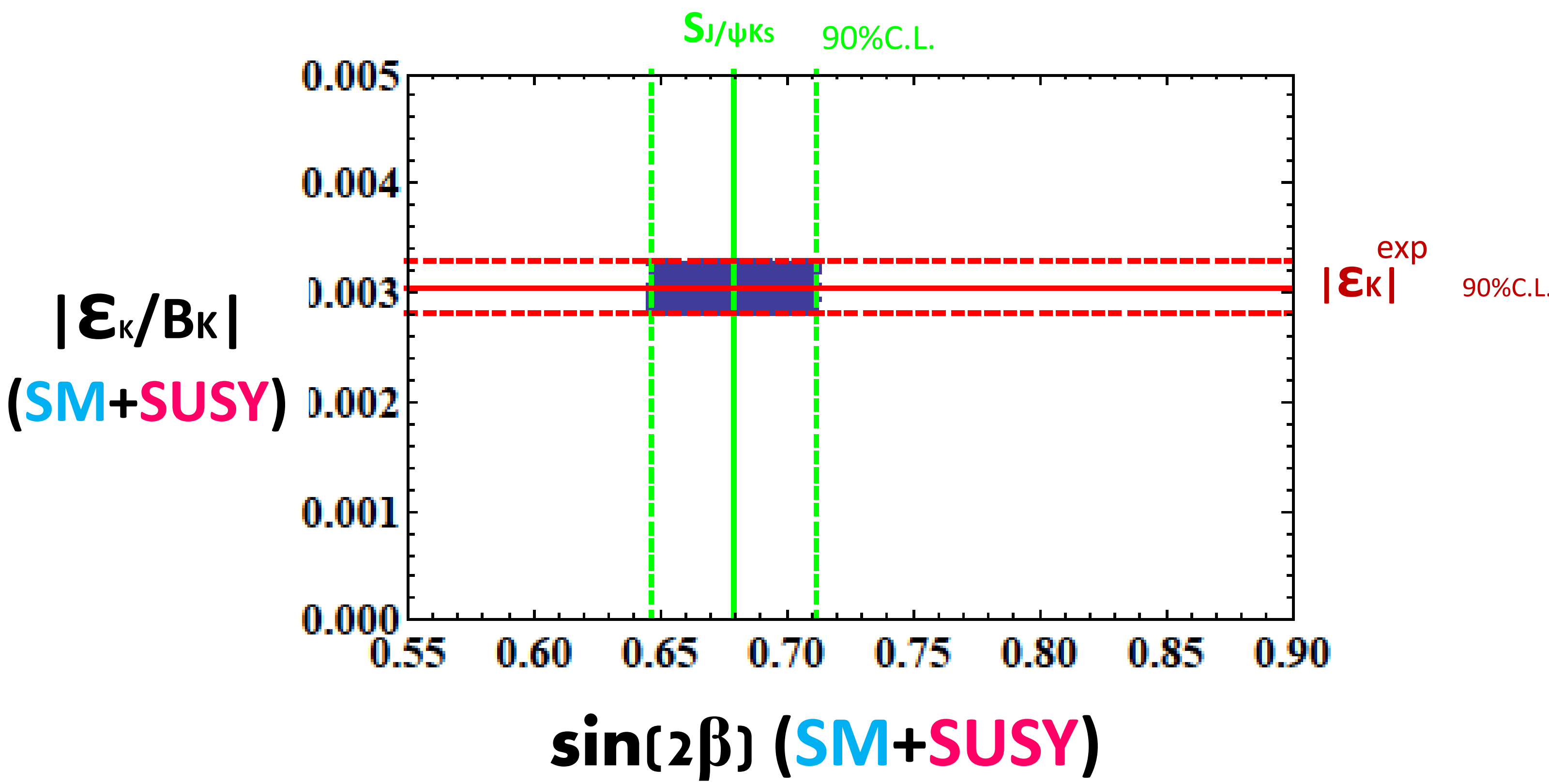
Numerical results

$S_{J/\psi K_S}$-$|\varepsilon_K|$ tension



Numerical results

$S_{J/\psi K_S}$-$|\varepsilon_K|$ tension



Targets

K meson | B meson | Bs meson

ΔF=2 : Mixing

$|\epsilon_K|$ ΔM_d ΔM_s

$S_{J/\psi K_S}$-$|\epsilon_K|$ tension

ΔF=1 : Time dependent CP asymmetry

$S_{J/\psi K_S}$ $S_{J/\psi\phi}$

$S_{\phi K_S}, S_{\eta' K^0}$ $S_{\phi\phi,\eta'\phi}$

$S_{K^0\bar{K}^0}$

Constraints for
SUSY mixing parameter
$\delta_{13}^{\mathrm{dL}}, \delta_{23}^{\mathrm{dL}}, \delta_{13}^{\mathrm{dR}}, \delta_{23}^{\mathrm{dR}}$

: Branching ratio

$\mathrm{BR}(b \to s\gamma)$

: CP asymmetry in the semileptonic decay

a_{sl}^d a_{sl}^s

Step2

Prediction

ΔF=0 : Chromo EDM of strange quark

$|d_s^C|$

S_f Time dependent CP asymmetry in $B_q \to f$

$$\mathcal{A} = \frac{\Gamma\left(B^0(t) \to f\right) - \Gamma\left(\bar{B}^0(t) \to f\right)}{\Gamma\left(B^0(t) \to f\right) + \Gamma\left(\bar{B}^0(t) \to f\right)}$$

$$= \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1} \cos\left(\Delta m_B t\right) + \underbrace{\frac{2\mathrm{Im}\lambda}{|\lambda|^2 + 1}}_{S_f} \sin\left(\Delta m_B t\right)$$

$$\lambda = \frac{q}{p} \frac{\bar{A}^{SM} + \bar{A}^{SUSY}}{A^{SM} + A^{SUSY}}$$

mixing part **amplitude part**

$$A(B_q \to f) \simeq \sum_i C_i O_i$$

C_i : Wilson coefficients

$$C_i = C_i(\mathrm{SM}) + C_i(\mathrm{NP})$$

O_i : Local operator

$$\lambda_{\phi K_S, \eta' K^0} = \mathrm{Sin}(2\beta_{SM} + \mathrm{Arg}(1 + h_d e^{2i\sigma_d})) \frac{\sum_{i=3-6,7\gamma,8G} \left(C_i^{\mathrm{SM}} \langle O_i \rangle + C_i^{\tilde{g}} \langle O_i \rangle + \widetilde{C}_i^{\tilde{g}} \langle \widetilde{O}_i \rangle\right)}{\sum_{i=3-6,7\gamma,8G} \left(C_i^{\mathrm{SM}*} \langle O_i \rangle + C_i^{\tilde{g}*} \langle O_i \rangle + \widetilde{C}_i^{\tilde{g}*} \langle \widetilde{O}_i \rangle\right)}$$

We focus on a few modes which decay at 1-loop level in SM ,
because it is expected that SUSY contribution will be enhanced.

Predictions

$S_{\phi K_S}, S_{\eta' K^0}$ Time dependent CP asymmetry in $B_d \to \phi K_S, \eta' K^0$

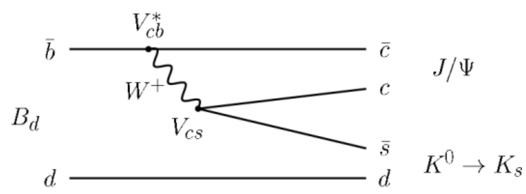
SM prediction

$$S_{J/\psi K_S} \simeq S_{\phi K_S, \eta' K_S}$$

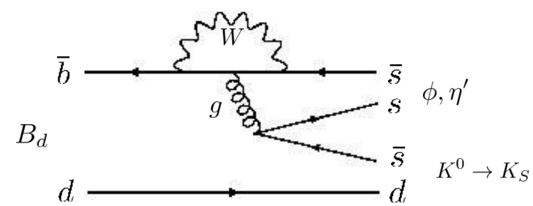
Experimental results [HFAG,2012]

$$S_{J/\psi K_S} = 0.679 \pm 0.020$$
$$S_{\phi K_S} = 0.74^{+0.11}_{-0.13}$$
$$S_{\eta' K^0} = 0.59 \pm 0.07$$

$B_d \to J/\psi K_S$



$B_d \to \phi K_S, \eta' K^0$



Both CP violations come from CP phase in the B_d^0–$\bar{B}_d^0$ mixing.

SUSY contribution

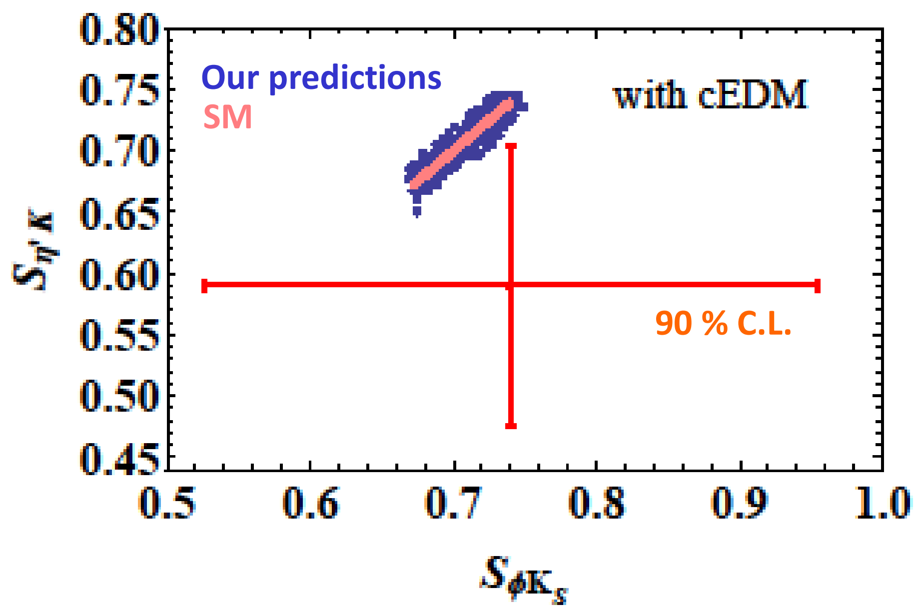
$$A^{SUSY}\left(\bar{B}_d \to \phi K_s\right) \propto C_{8G}^{\tilde{g}}(m_b) + \tilde{C}_{8G}^{\tilde{g}}(m_b)$$
$$A^{SUSY}\left(\bar{B}_d \to \eta' K_s\right) \propto C_{8G}^{\tilde{g}}(m_b) - \tilde{C}_{8G}^{\tilde{g}}(m_b)$$

$\tilde{C} : C(L \Leftrightarrow R)$ Depends on δ_{23}^d

Difference of sign comes from parity of final state.

[M.Endo, S.Mishima and M.Yamaguchi, PLB 609 (2005)]

Our prediction



Predictions

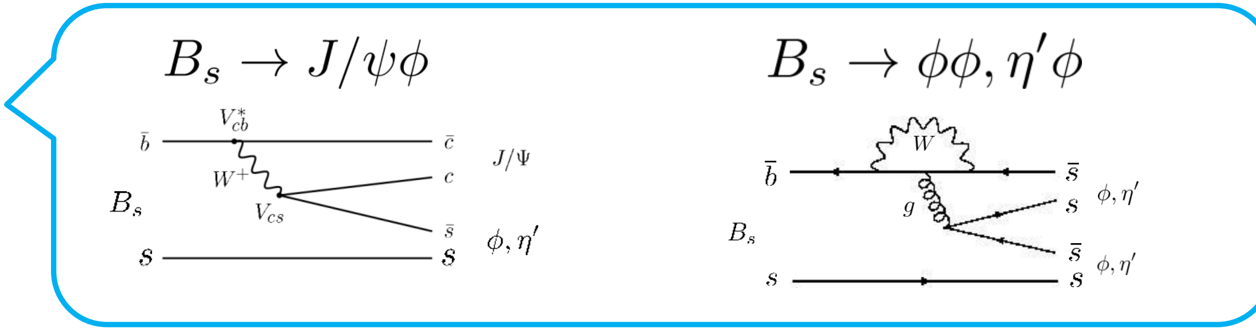
$S_{\phi\phi}, S_{\eta'\phi}$ Time dependent CP asymmetry in $B_s \to \phi\phi, \eta'\phi$

SM prediction

$$S_{J/\psi\phi} = \sin\phi_s$$

$$\phi_s(\mathrm{SM}) = -0.0363 \pm 0.0017$$

$$S_{\phi\phi,\eta'\phi} \simeq \mathcal{O}(\lambda^4)$$



Experimental results

$S_{J/\psi\phi}$ [LHCb, Phys. Rev. D 87, 112010(2013)]

$$\phi_s(\mathrm{Exp}) = 0.07 \pm 0.09 \pm 0.01$$

$S_{\phi\phi}$ [LHCb, Phys.Rev.Lett.110, 241802 (2013)]

$$\phi_s(\phi\phi) = [-2.46, -0.76](68\%\mathrm{C.L.})$$ **New !**

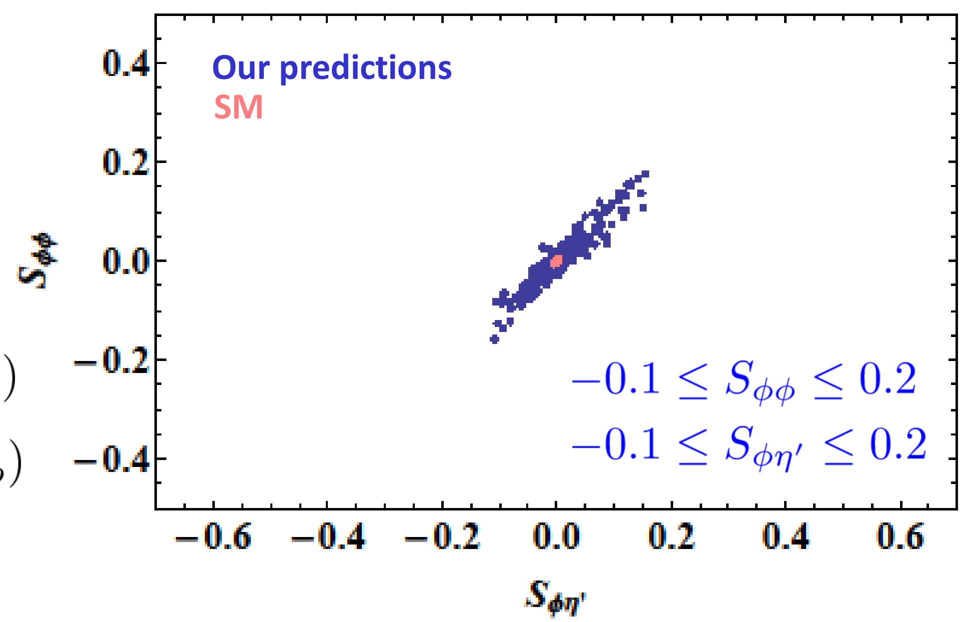
SUSY contribution

$$A^{SUSY}\left(\bar{B}_s \to \phi\phi\right) \propto C_{8G}^{\tilde{g}}(m_b) - \tilde{C}_{8G}^{\tilde{g}}(m_b)$$

$$A^{SUSY}\left(\bar{B}_s \to \phi\eta'\right) \propto C_{8G}^{\tilde{g}}(m_b) + \tilde{C}_{8G}^{\tilde{g}}(m_b)$$

Depends on δ_{23}^d

Our prediction



Predictions

$S_{\phi\phi}, S_{\eta'\phi}$ Time dependent CP asymmetry in $B_s \to \phi\phi, \eta'\phi$

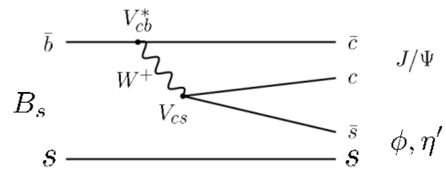
SM prediction

$$S_{J/\psi\phi} = \sin\phi_s$$

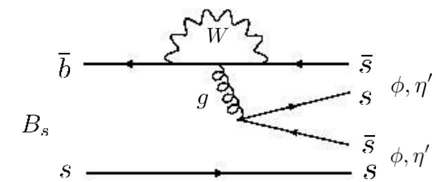
$$\phi_s(\mathrm{SM}) = -0.0363 \pm 0.0017$$

$$S_{\phi\phi,\eta'\phi} \simeq \mathcal{O}(\lambda^4)$$

$B_s \to J/\psi\phi$

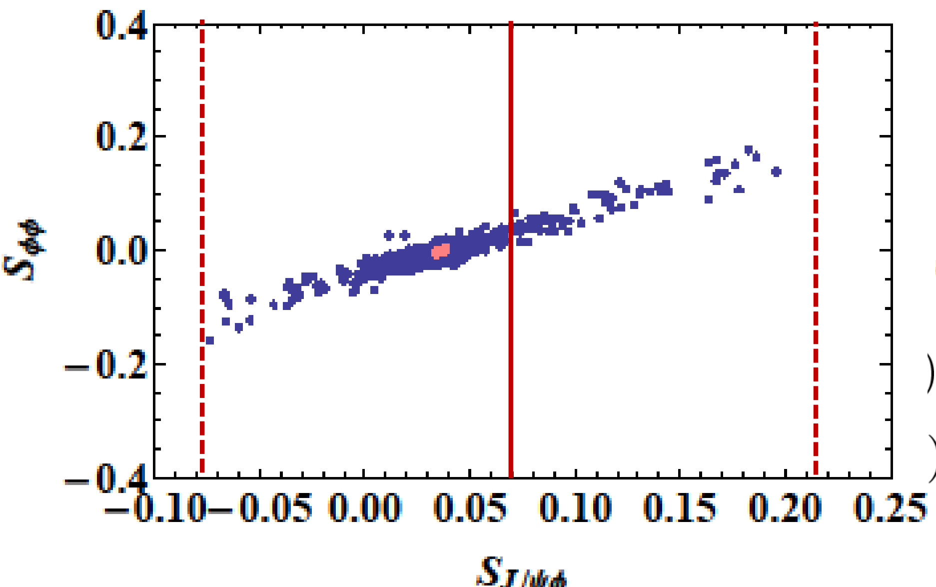


$B_s \to \phi\phi, \eta'\phi$

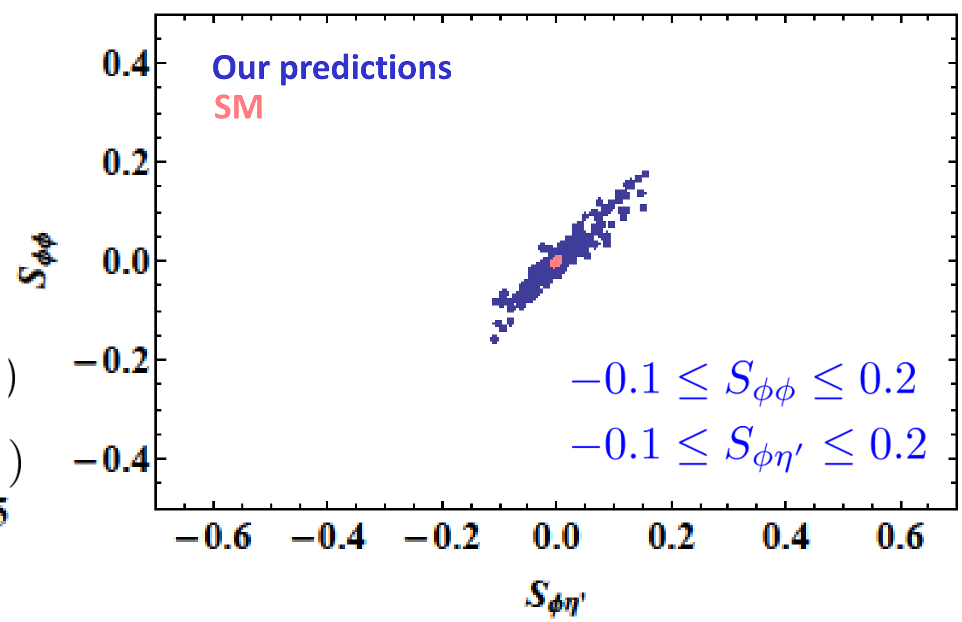


Experimental results

$S_{J/\psi\phi}$ [LHCb, Phys. Rev. D 87, 112010(2013)]



Our prediction

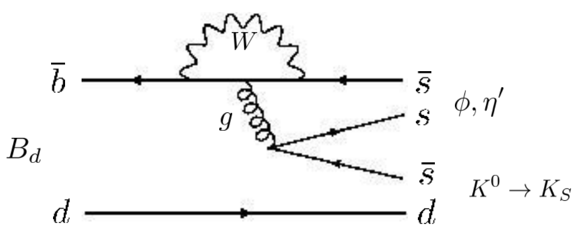


Depends on θ_{23}

Predictions

$S_{K^0\bar{K}^0}$ Time dependent CP asymmetry in $B_d \to K^0\bar{K}^0$

Standard model



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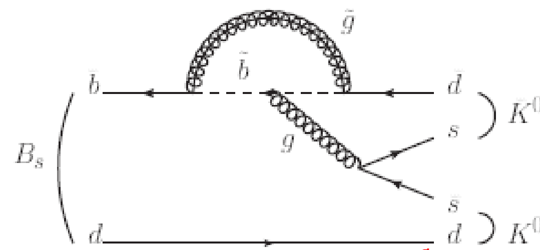
The gluino-sbottom-quark interaction



Depends on δ_{13}^{d}

SM prediction [A.K.Giri and R.Mohanta, JHEP 0411 (2004) 084]

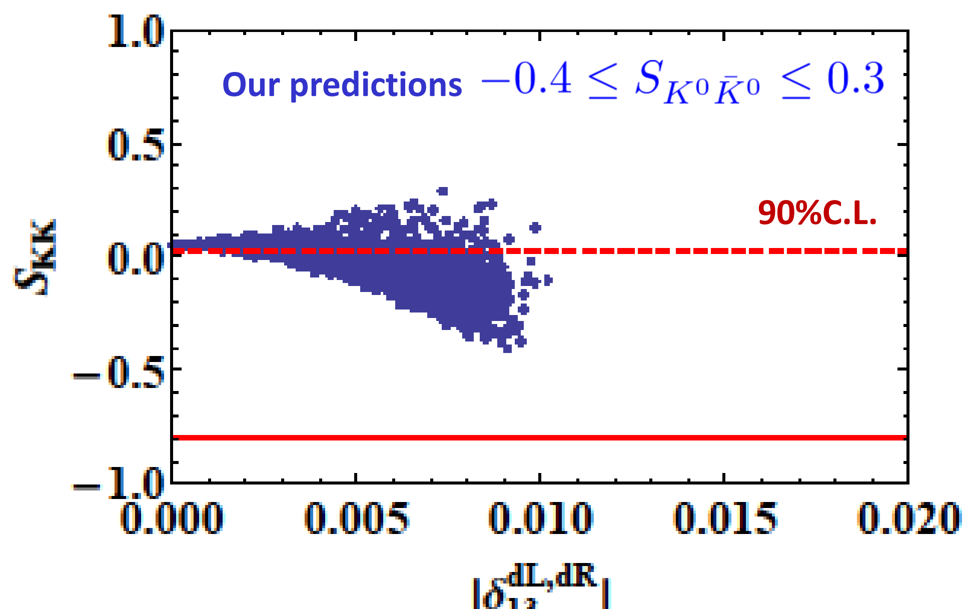
$$S_{K^0\bar{K}^0}(\mathrm{SM}) \simeq 0.06$$

with pQCD

Experimental result [PDG 2012]

$$S_{K^0\bar{K}^0}(\exp) = -0.8 \pm 0.5$$

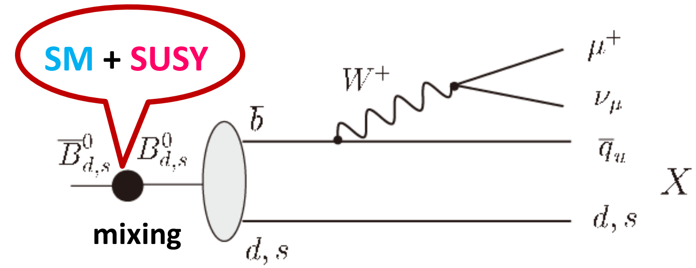
Our prediction



Predictions

$$\boxed{a_{sl}^d, a_{sl}^s}$$ CP asymmetry in the semileptonic decay $\overline{B}_q^0 \Longrightarrow B_q^0 \to \mu^+ X$

$$a_{sl}^q \equiv \frac{\Gamma\left(\overline{B}_q^0 \to \mu^+ X\right) - \Gamma\left(B_q^0 \to \mu^- X\right)}{\Gamma\left(\overline{B}_q^0 \to \mu^+ X\right) + \Gamma\left(B_q^0 \to \mu^- X\right)}$$
$$= \frac{1 - \left|\frac{p}{q}\right|^4}{1 + \left|\frac{p}{q}\right|^4} = -\mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)$$



a_{sl}^d **depends on** δ_{13}^d a_{sl}^s **depends on** δ_{23}^d

SM predictions

[A.Lenz and U.Nierste, arXiv:1102.4274 [hep -ph]]

$$a_{sl}^{s,\mathrm{SM}} = (1.9 \pm 0.3) \times 10^{-5}$$
$$a_{sl}^{d\mathrm{SM}} = -(4.1 \pm 0.6) \times 10^{-4}$$

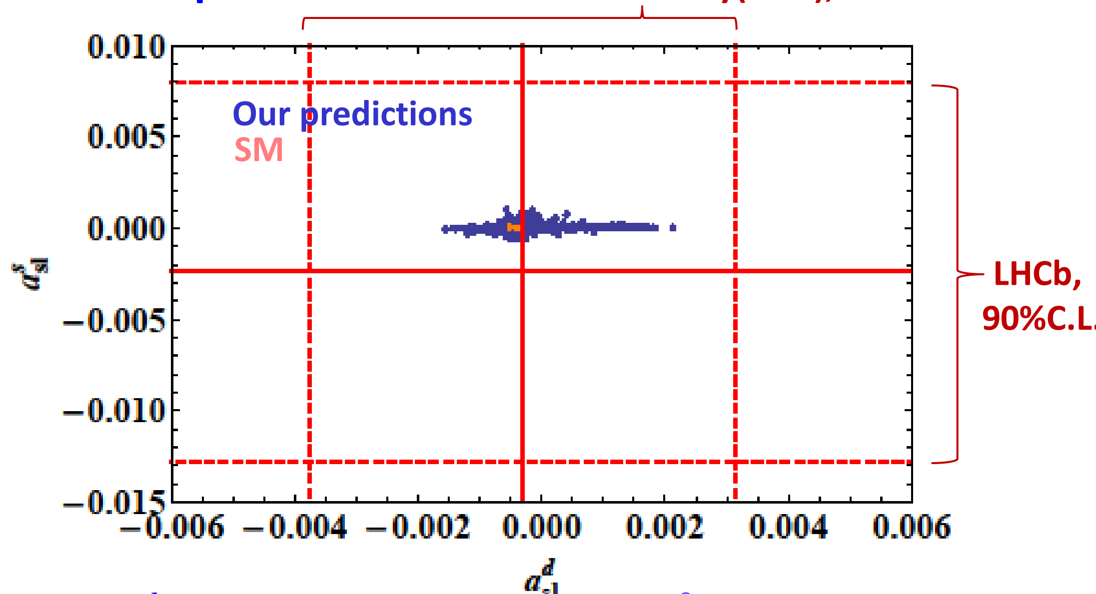
Experimental results

[PDG 2012]

$$a_{sl}^s = (-0.24 \pm 0.54 \pm 0.33) \times 10^{-2}$$
$$a_{sl}^d = (-0.3 \pm 2.1) \times 10^{-3}$$

Our predictions

B factory(PDG), 90%C.L.



$a_{sl}^d = -0.0017 \sim 0.002$ $a_{sl}^s = -0.001 \sim 0.001$

Summary

We have discussed the sensitivity of the gluino-sbottom-quark interaction to the CP violating phenomena of the K , B^0 and B_s mesons.

We take the natural SUSY scenario, which is consistent with the experimental situation of LHC.

$$m_{\tilde{q}_{1,2}} = \mathcal{O}(10)\ \mathrm{TeV}, \quad m_{\tilde{b}_1} = 1\ \mathrm{TeV}, m_{\tilde{b}_2} = 1.1\ \mathrm{TeV}, \quad m_{\tilde{g}} = 2\ \mathrm{TeV}$$

The relevant constraints : $|\epsilon_K|, \quad \Delta M_d, \quad \Delta M_s, \quad S_{J/\psi K_S}, \quad S_{J/\psi\phi}, \quad \mathrm{BR}(b \to s\gamma), \quad |d_s^C|$

$\longrightarrow$ The allowed region of the mixing parameter

$$\boxed{|\delta_{13}^{dL(dR)}| = 0 \sim 0.01 \qquad |\delta_{23}^{dL(dR)}| = 0 \sim 0.04}$$

We predict $S_{\phi K_S}, S_{\eta' K^0}, \quad S_{\phi\phi}, S_{\eta'\phi}, \quad S_{K^0\bar{K}^0}, \quad a_{sl}^d, a_{sl}^s$

SUSY contributions to $S_{\phi K_S}, S_{\eta' K^0}$ is tiny,

$$-0.1 \leq S_{\phi\phi} \leq 0.2 \qquad -0.1 \leq S_{\phi\eta'} \leq 0.2$$
$$-0.4 \leq S_{K^0\bar{K}^0} \leq 0.3$$
$$a_{sl}^d = -0.0017 \sim 0.002 \qquad a_{sl}^s = -0.001 \sim 0.001$$

Our model will be tested by Belle II as well as LHCb.

Buckup

Mixing angle θ

Mass matrix $\tilde{m}^2_{\tilde{q}\mathrm{dia}} = \Gamma_G^{(q)} M^2_{\tilde{q}} \Gamma_G^{(q)\dagger}$

$$M^2_{\tilde{q}} = \begin{pmatrix} m^2_{\tilde{d}_L} & m_b(A_b - \mu\tan\beta) \\ m_b(A_b - \mu\tan\beta) & m^2_{\tilde{d}_R} \end{pmatrix}$$

Third family

$$\tan2\theta = \frac{2m_b(A_b - \mu\tan\beta)}{m^2_{\tilde{d}_L} - m^2_{\tilde{d}_R}}$$

ΔF=1

$$H_{eff} = \frac{4G_F}{\sqrt{2}} \left[\sum_{q'=u,c} V_{q'b} V^*_{q'q} \sum_{i=1,2} C_i O_i^{(q')} - V_{tb} V^*_{tq} \sum_{i=3-6,7\gamma,8G} \left(C_i O_i + \widetilde{C}_i \widetilde{O}_i \right) \right],$$

$$O_1^{(q')} = (\bar{q}_\alpha \gamma_\mu P_L q'_\beta)(\bar{q}'_\beta \gamma^\mu P_L b_\alpha), \qquad O_2^{(q')} = (\bar{q}_\alpha \gamma_\mu P_L q'_\alpha)(\bar{q}'_\beta \gamma^\mu P_L b_\beta),$$

$$O_3 = (\bar{q}_\alpha \gamma_\mu P_L b_\alpha) \sum_Q (\bar{Q}_\beta \gamma^\mu P_L Q_\beta), \quad O_4 = (\bar{q}_\alpha \gamma_\mu P_L b_\beta) \sum_Q (\bar{Q}_\beta \gamma^\mu P_L Q_\alpha),$$

$$O_5 = (\bar{q}_\alpha \gamma_\mu P_L b_\alpha) \sum_Q (\bar{Q}_\beta \gamma^\mu P_R Q_\beta), \quad O_6 = (\bar{q}_\alpha \gamma_\mu P_L b_\beta) \sum_Q (\bar{Q}_\beta \gamma^\mu P_R Q_\alpha),$$

$$O_{7\gamma} = \frac{e}{16\pi^2} m_b \bar{q}_\alpha \sigma^{\mu\nu} P_R b_\alpha F_{\mu\nu}, \qquad O_{8G} = \frac{g_s}{16\pi^2} m_b \bar{q}_\alpha \sigma^{\mu\nu} P_R T^a_{\alpha\beta} b_\beta G^a_{\mu\nu},$$

ΔF=1

Most dominant term comes from $C_{8G}^{\tilde{g}}$.

$$A^{SUSY}\left(\bar{B}_d \to \phi K_s\right) \propto C_{8G}^{\tilde{g}}\left(m_b\right) + \tilde{C}_{8G}^{\tilde{g}}\left(m_b\right)$$

$\tilde{C} : C(L \Leftrightarrow R)$

$$C_{8G}^{\tilde{g}}(m_{\tilde{g}}) = \frac{8}{3}\frac{\sqrt{2}\alpha_s\pi}{2G_F V_{tb}V_{tq}^*}\left[\frac{\left(\Gamma_{GL}^{(d)}\right)_{k3}^*}{m_{\tilde{d}_3}^2}\left\{\left(\Gamma_{GL}^{(d)}\right)_{33}\left(-\frac{9}{8}F_1(x_{\tilde{g}}^3) - \frac{1}{8}F_2(x_{\tilde{g}}^3)\right)\right.\right.$$

$$\left.+\frac{m_{\tilde{g}}}{m_b}\left(\Gamma_{GR}^{(d)}\right)_{33}\left(-\frac{9}{8}F_3(x_{\tilde{g}}^3) - \frac{1}{8}F_4(x_{\tilde{g}}^3)\right)\right\}$$

$$+\frac{\left(\Gamma_{GL}^{(d)}\right)_{k6}^*}{m_{\tilde{d}_6}^2}\left\{\left(\Gamma_{GL}^{(d)}\right)_{36}\left(-\frac{9}{8}F_1(x_{\tilde{g}}^6) - \frac{1}{8}F_2(x_{\tilde{g}}^6)\right)\right.$$

$$\left.\left.+\frac{m_{\tilde{g}}}{m_b}\left(\Gamma_{GR}^{(d)}\right)_{36}\left(-\frac{9}{8}F_3(x_{\tilde{g}}^6) - \frac{1}{8}F_4(x_{\tilde{g}}^6)\right)\right\}\right],$$

$\delta_{23}^{dL} s_\theta c_\theta e^{-i\phi}$

$-\delta_{23}^{dL} s_\theta c_\theta e^{-i\phi}$

$$x = \frac{m_{\tilde{g}}^2}{m_{\tilde{d}_1}^2}$$

If two masses $m_{\tilde{b}_1}, m_{\tilde{b}_2}$ degenerate, we have complete cancellation.

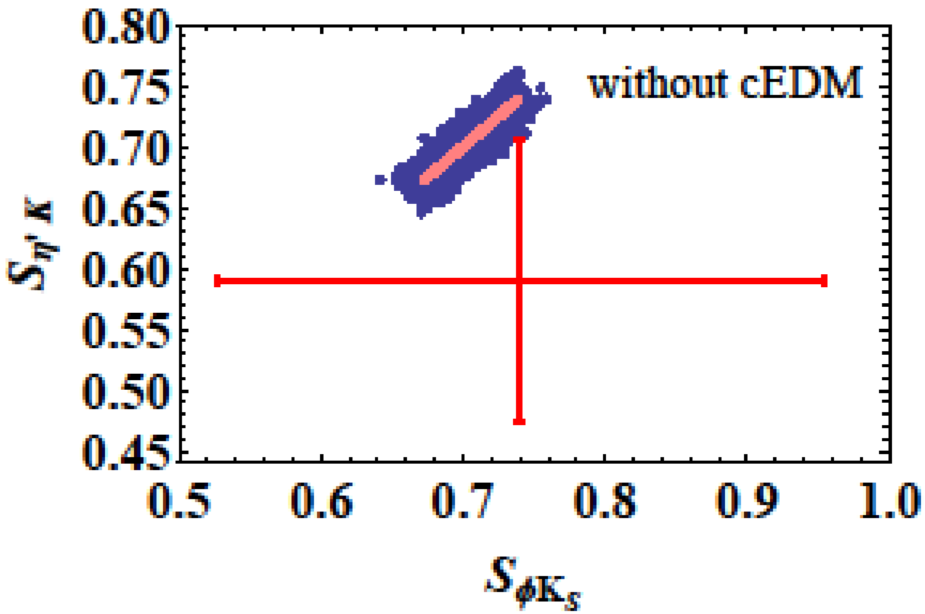
$C_{8G}^{\tilde{g}}$ is reduced by this cancellation.

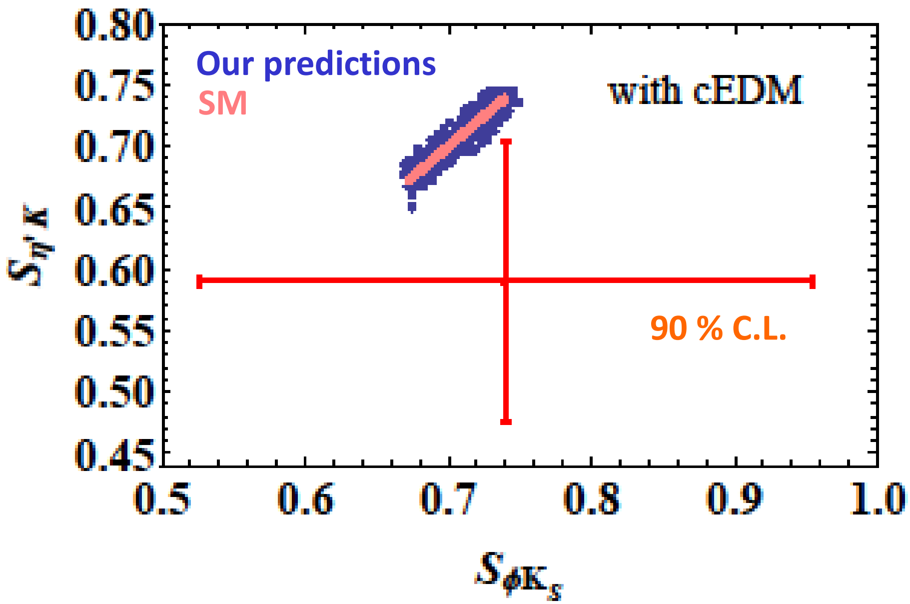
Factorization relation

$$\langle O_3 \rangle = \langle O_4 \rangle = \left(1 + \frac{1}{N_c}\right) \langle O_5 \rangle, \quad \langle O_6 \rangle = \frac{1}{N_c} \langle O_5 \rangle,$$

$$\langle O_{8G} \rangle = \frac{\alpha_s(m_b)}{8\pi} \left(-\frac{2m_b}{\sqrt{\langle q^2 \rangle}}\right) \left(\langle O_4 \rangle + \langle O_6 \rangle - \frac{1}{N_c}(\langle O_3 \rangle + \langle O_5 \rangle)\right),$$

The effect of cEDM of the strange quark

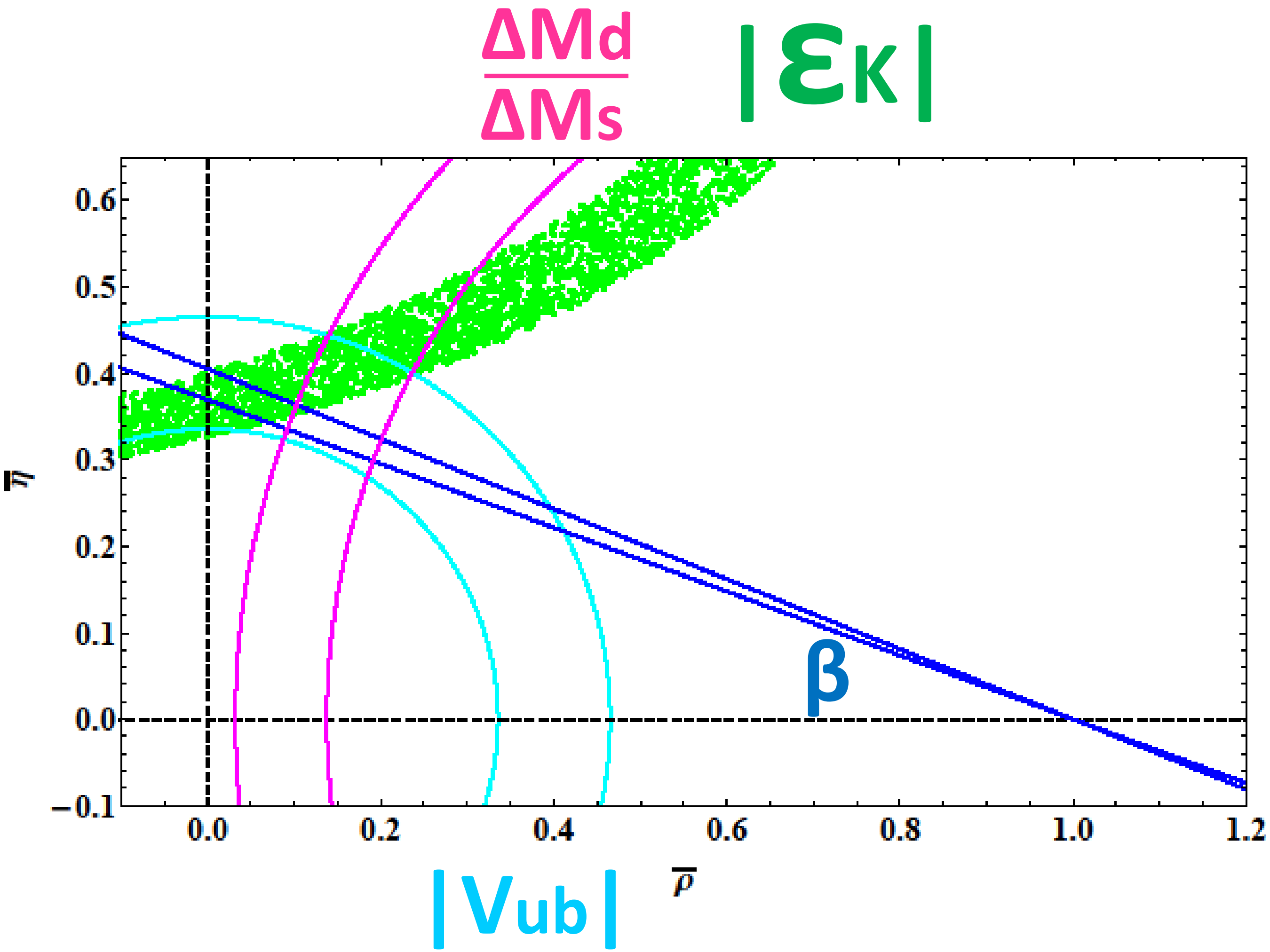




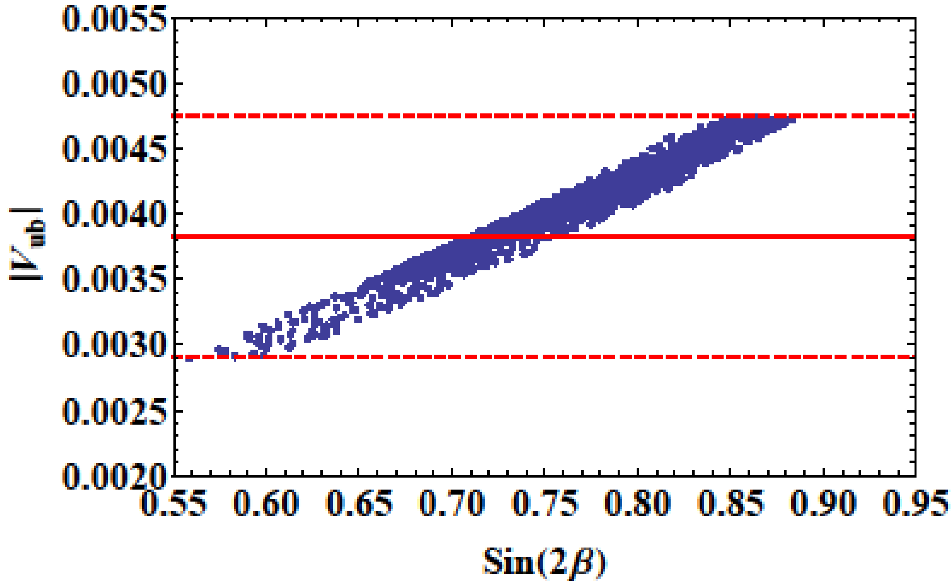
Input parameters

$$\alpha_s(M_Z) = 0.1184 \ [34]$$
$$m_c(m_c) = 1.275 \text{ GeV } [34]$$
$$m_t(m_c) = 1.275 \text{ GeV } (\bar{MS}) \ [34]$$
$$M_{B_s} = 5.36677(24) \text{ GeV } [34]$$
$$\Delta M_s = (116.942 \pm 0.1564) \times 10^{-13} \text{ GeV } [7]$$
$$\Delta M_d = (3.337 \pm 0.033) \times 10^{-13} \text{ GeV } [34]$$
$$f_{B_s} = (233 \pm 10) \text{ MeV } [47]$$
$$f_{B_s}/f_{B^0} = 1.200 \pm 0.02 \ [47]$$
$$\xi_s = 1.21(6) \ [26]$$
$$\lambda = 0.2255(7) \ [34]$$
$$|V_{cb}| = (4.12 \pm 0.11) \times 10^{-2} \ [47]$$
$$\eta_{cc} = 1.43(23) \ [26]$$
$$\eta_{ct} = 0.47(4) \ [26]$$
$$\eta_{tt} = 0.5765(65) \ [26]$$
$$f_K = (156.1 \pm 1.1) \text{ MeV } [34]$$
$$\kappa_\epsilon = 0.92(2) \ [26]$$

The unitarity triangle



(Exclusive decay & Inclusive decay)



0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
0.0025
0.0020
$|V_{ub}|$
0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95
Sin(2β)