Squark flavor mixing in B decays

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Based on: **arXiv:1404.0520** **with M.Tanimoto** (Niigata Univ.)

1. Introduction

- Higgs Discovery 2012 $m_H \simeq 126\mathrm{GeV}$

- No evidence of SUSY

  SUSY scale may be much higher than 1 TeV

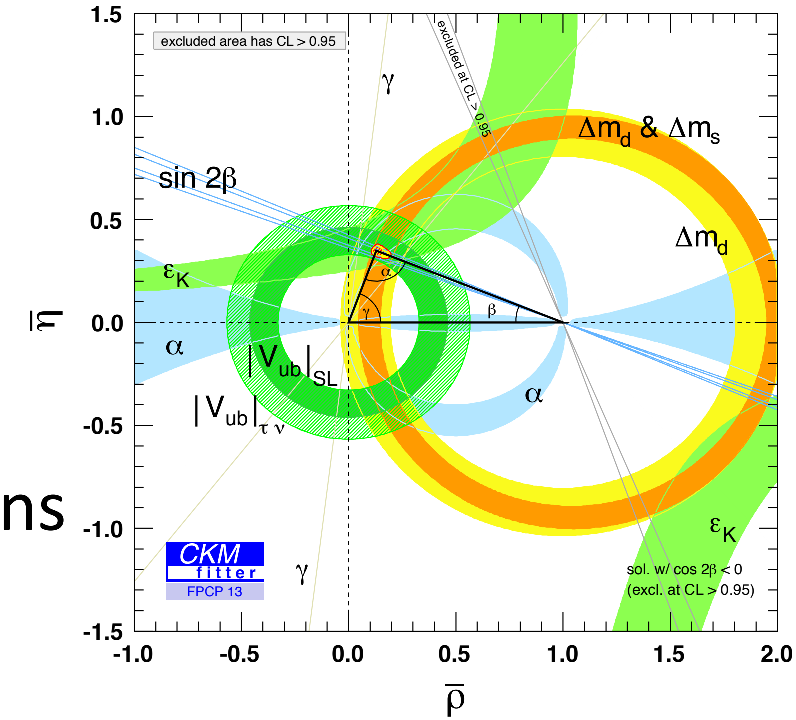
- We need indirect Search for SUSY

  ➡ Flavor physics

1. Introduction

- SM explains CP violation of K and B mesons successfully

- No significant deviation, but
  - a number of tensions
  - future measurements can improve a lot



- $\mathcal{O}(20\%)$ New Physics contributions to loop processes are still possible

We examine the sensitivity of High Scale SUSY in the CP violations of K and B mesons

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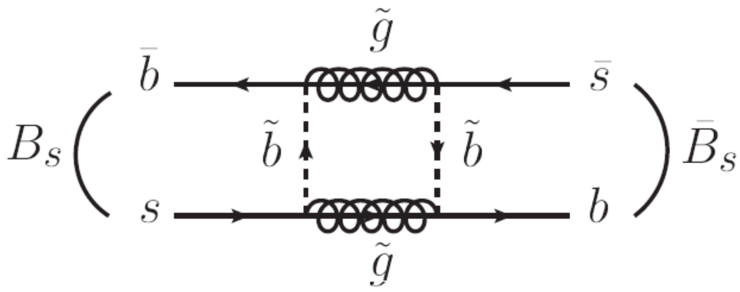
2. Squark Mass Spectrum

- We consider squark-gluino interactions in B meson system

Ex) ΔM_s



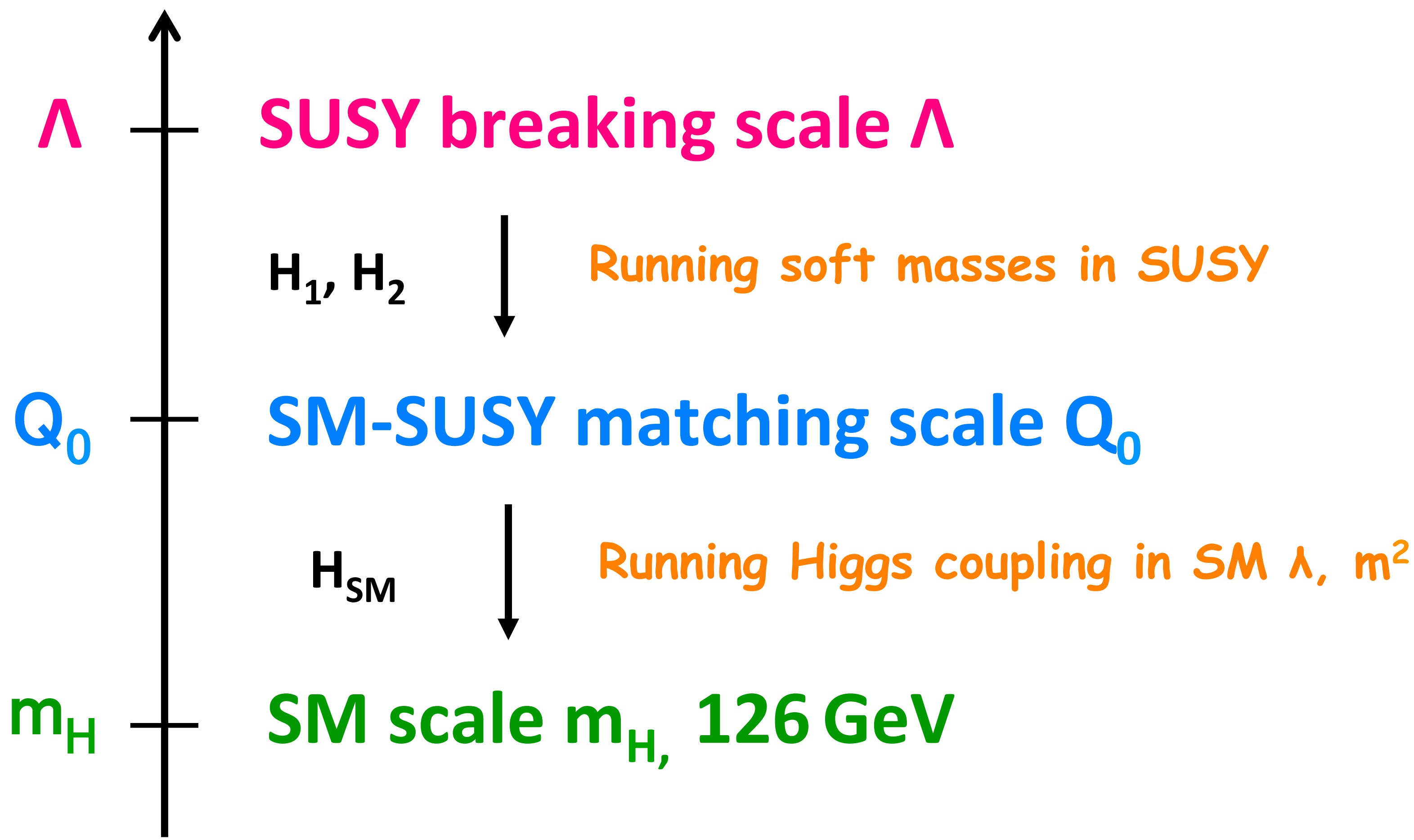
which depends on the squark and gluino mass spectrum

◇**SUSY-GIM works**

◇**Left-right mixing of sbottom is important**

◇**Loop functions depend on sbottom-gluino mass ratio**

We should consider SUSY particle spectrum, which is consistent with Higgs Discovery.



[Delgado, Garcia, Quiros, arXiv:1312.3235]

The quadratic terms in the MSSM potential

Λ

$$V_2 = m_1^2|H_1|^2 + m_2^2|H_2|^2 + m_3^2(H_1 \cdot H_2 + h.c.)$$

$$m_1^2 = m_{H_1}^2 + |\mu|^2 \qquad m_2^2 = m_{H_2}^2 + |\mu|^2$$

$$m_\pm^2 = \frac{m_1^2+m_2^2}{2} \pm \sqrt{\left(\frac{m_1^2-m_2^2}{2}\right) + m_3^2}$$

Q_0

Below Q_0 scale, SM

$$V_{\rm SM} = -m^2|H|^2 + \frac{\lambda}{2}|H|^4$$

We put the matching condition

$$m_-^2 = -m^2(Q_0) \quad \text{and} \quad m_+^2 = m_1^2 + m_2^2 + m^2 \equiv m_{\mathcal{H}}^2$$

by the fixing $m_3^4 = (m_1^2 + m^2)(m_2^2 + m^2)$

[Delgado, Garcia, Quiros, arXiv:1312.3235]

Q_0

$$m^2 = \frac{m_1^2 - m_2^2 \tan^2\beta}{\tan^2\beta - 1}$$

$$\lambda = \frac{1}{4}(g^2 + g'^2)\cos^2 2\beta + \frac{3h_t^2}{8\pi^2} X_t^2 \left(1 - \frac{X_t^2}{12}\right)$$

$$X_t = \frac{A_t(Q_0) - \mu(Q_0)\cot\beta}{Q_0}$$

$$m_{\mathcal{H}}^2 = Q_0^2$$
$$\mu(Q_0) = Q_0$$

RGE's

SM Higgs $\quad H = \cos\beta H_1 + \sin\beta \tilde{H}_2$

Heavy Higgs $\quad \mathcal{H} = -\sin\beta H_1 + \cos\beta \tilde{H}_2$

m_H

$$m_H^2 = \lambda(m_H)v^2 = 2m^2(m_H), \qquad v = 246\text{GeV}$$

$(126\ \text{GeV})^2$

(where $< H_1 >= v_d = v\cos\beta$, $< H_2 >= v_u = v\sin\beta$ $\Rightarrow$ $< H >= v$, $< \mathcal{H} >= 0$)

- Taking universal soft parameters at SUSY breaking scale Λ (gravity mediated-like model)

$$
\begin{aligned}
&m^2_{\tilde{Q}_i}(\Lambda) = m^2_{\tilde{U}^c_i}(\Lambda) = m^2_{\tilde{D}^c_i}(\Lambda) = m_0^2 \ (i = 1, 2, 3) \ , \\
&M_1(\Lambda) = M_2(\Lambda) = M_3(\Lambda) = m_{1/2}, \ , \\
&m^2_{H_1}(\Lambda) = m^2_{H_2}(\Lambda) = m_0^2 \ , \\
&A_U(\Lambda) = A_0 y_U(\Lambda), \quad A_D(\Lambda) = A_0 y_D(\Lambda), \quad A_E(\Lambda) = A_0 y_E(\Lambda).
\end{aligned}
$$

6 parameters taking with $\mu = Q_0$

Λ, Q_0 , tanβ, m_0, $m_{1/2}$, A_0

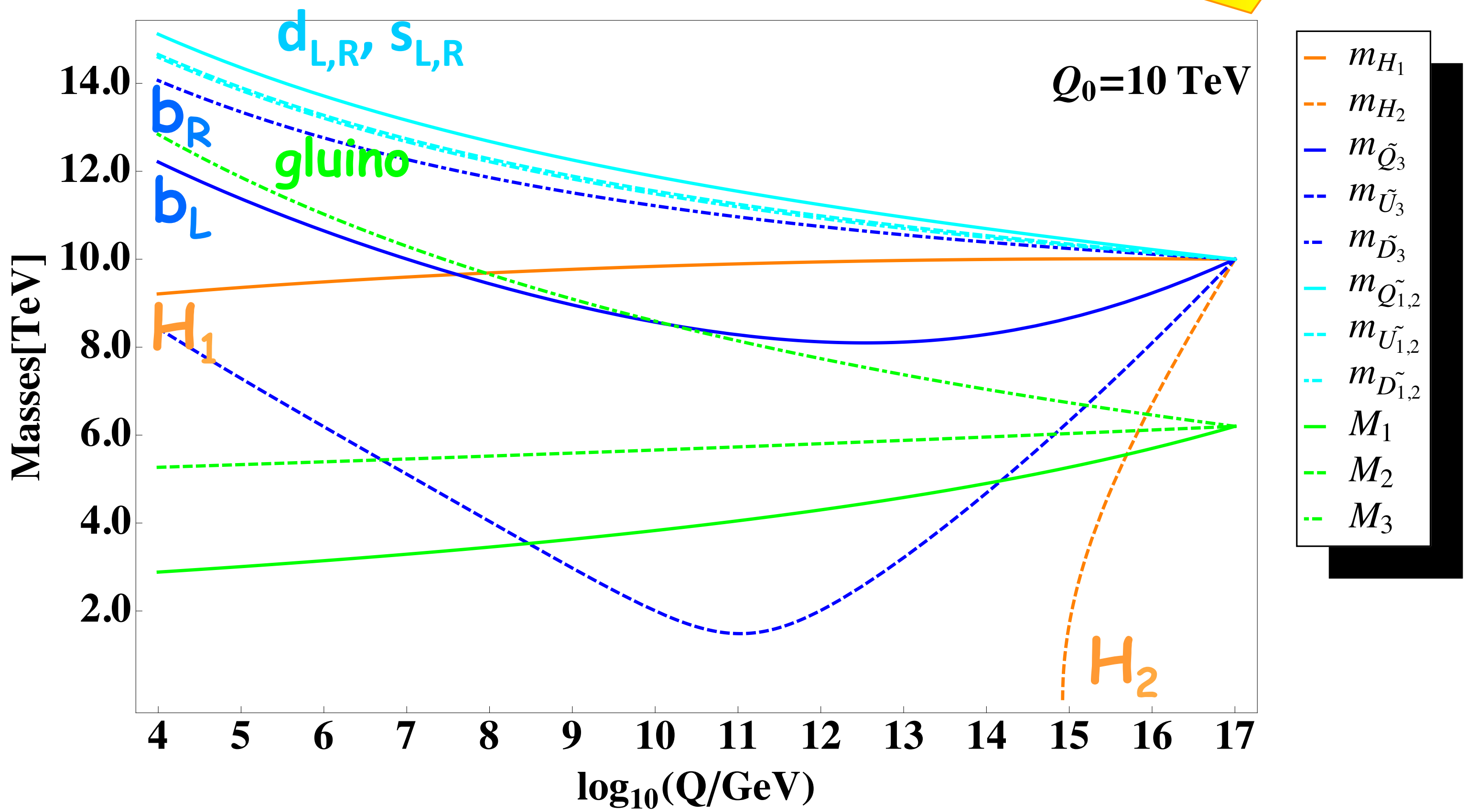
- We tune $m_{1/2}$ and At to give m_H=126 GeV

$$Q_0 = 10\text{TeV} \qquad \Lambda = 10^{17}\text{TeV}$$

RGE running

at $Q_0 = 10$ TeV,
$\mu = 10$ TeV,
$\tan\beta = 10$

at $\Lambda = 10^{17}$ GeV,
$m_0 = 10$ TeV,
$m_{1/2} = 6.2$ TeV,
$A_0 = 25.803$ TeV;



RGE running

at $Q_0 = 10$ TeV,
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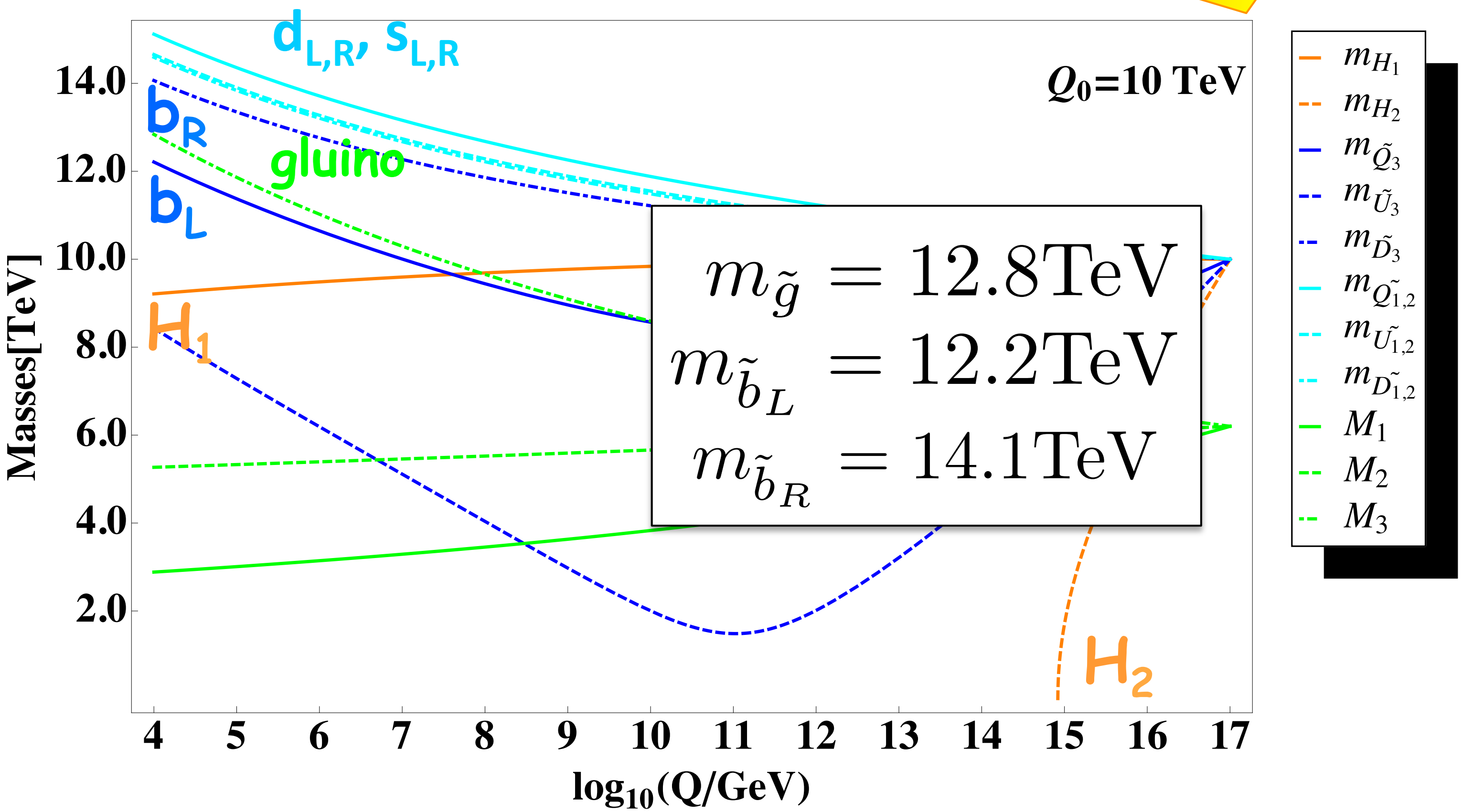
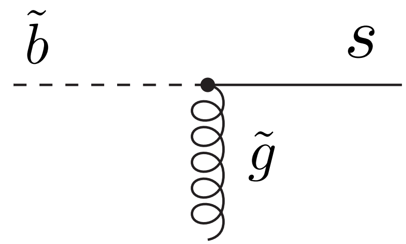


Squark flavor mixing

- The gluino-squark-quark interaction



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

Rotation matrix :

$$\Gamma^{(d)}_{GL} = \begin{pmatrix} c^L_{13} & 0 & s^L_{13}e^{-i\phi^L_{13}}c_\theta & 0 & 0 & -s^L_{13}e^{-i\phi^L_{13}}s_\theta e^{i\phi} \\ -s^L_{23}s^L_{13}e^{i(\phi^L_{13}-\phi^L_{23})} & c^L_{23} & s^L_{23}c^L_{13}e^{-i\phi^L_{23}}c_\theta & 0 & 0 & -s^L_{23}c^L_{13}e^{-i\phi^L_{23}}s_\theta e^{i\phi} \\ -s^L_{13}c^L_{23}e^{i\phi^L_{13}} & -s^L_{23}e^{i\phi^L_{23}} & c^L_{13}c^L_{23}c_\theta & 0 & 0 & -c^L_{13}c^L_{23}s_\theta e^{i\phi} \end{pmatrix} \quad q_L$$

6 squarks

$$\Gamma^{(d)}_{GR} = \begin{pmatrix} 0 & 0 & s^R_{13}s_\theta e^{-i\phi^R_{13}}e^{-i\phi} & c^R_{13} & 0 & s^R_{13}e^{-i\phi^R_{13}}c_\theta \\ 0 & 0 & s^R_{23}c^R_{13}s_\theta e^{-i\phi^R_{23}}e^{-i\phi} & -s^R_{13}s^R_{23}e^{i(\phi^R_{13}-\phi^R_{23})} & c^R_{23} & s^R_{23}c^R_{13}e^{-i\phi^R_{23}}c_\theta \\ 0 & 0 & c^R_{13}c^R_{23}s_\theta e^{-i\phi} & -s^R_{13}c^R_{23}e^{i\phi^R_{13}} & -s^R_{23}e^{i\phi^R_{23}} & c^R_{13}c^R_{23}c_\theta \end{pmatrix} \quad q_R$$

- 1st and 2nd family squarks are degenerate: $s_{12}=0$
- Parameters

Setup

Mixing parameter: $s^L_{23},\ s^R_{23},\ s^L_{13},\ s^R_{13} \longrightarrow \quad |s^L_{23}| = |s^R_{23}| \quad |s^L_{13}| = |s^R_{13}|$

Phase: ϕ

Left-Right mixing angle: θ

Left-Right mixing angle θ

- Remark:
  Dominant contributions of C_{8G}, $C_{7\gamma}$ and cEDM come from Left-Right mixing θ

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

Third family

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

$$\theta = 0.35^\circ$$

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3. **CP violations of K and B**
   chromo-EDM of strange quark

4. Summary

Our strategy

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

ΔF=0 : Chromo EDM of strange quark

$$\lvert d_s^C\rvert$$

Our strategy

	K meson	B meson	Bs meson
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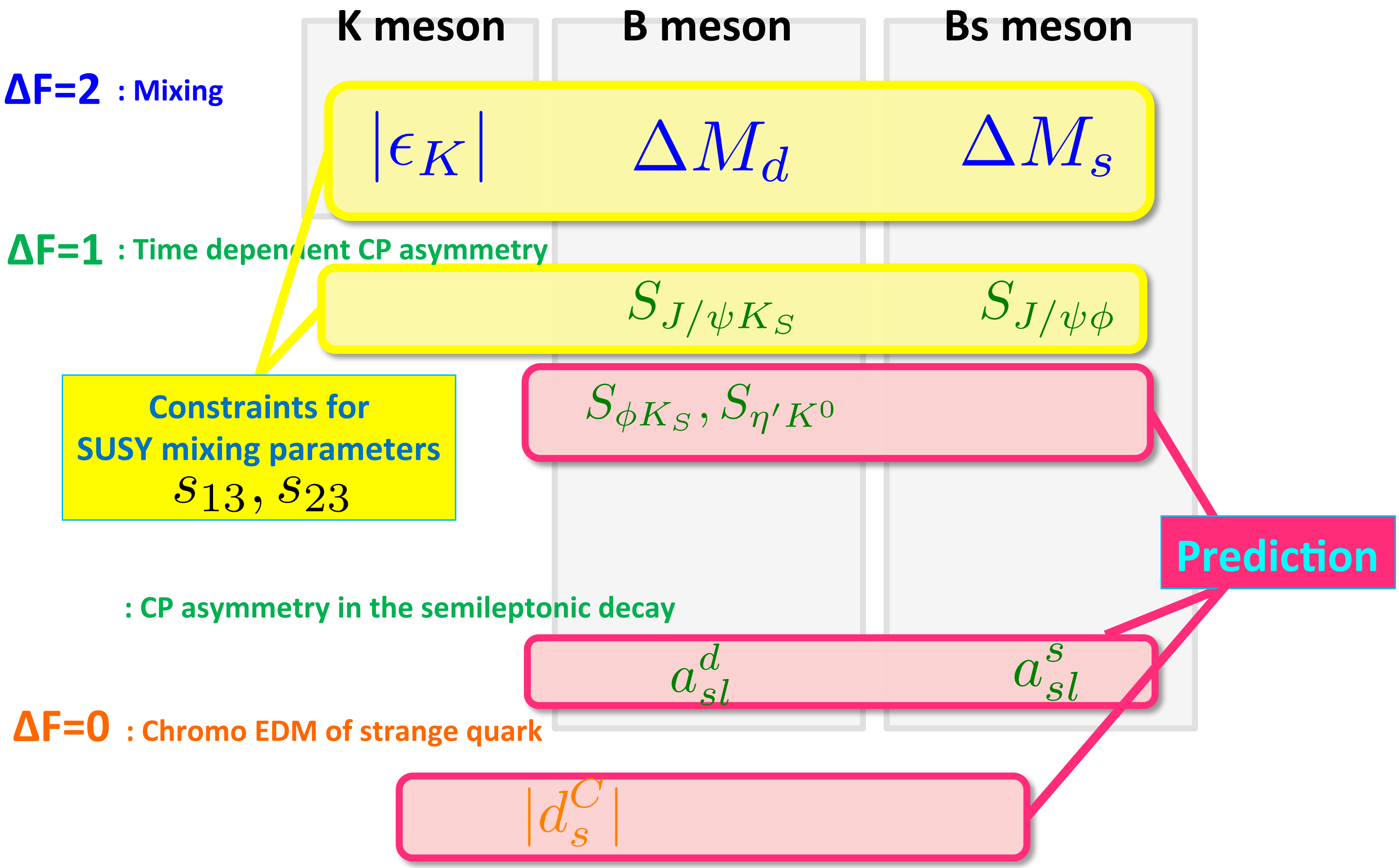
ΔF=0 : Chromo EDM of strange quark

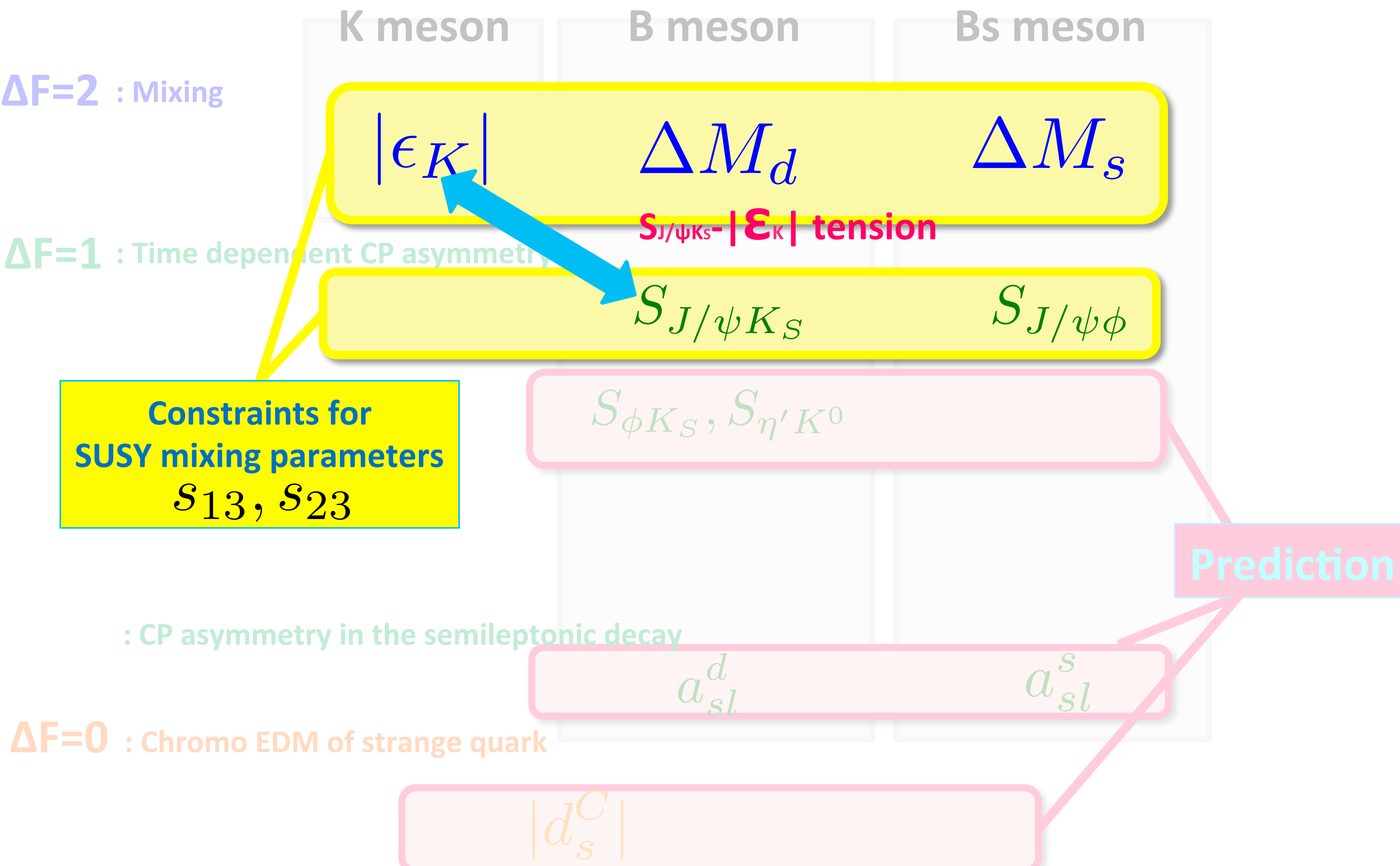
$\lvert d_s^C \rvert$

Constraints for SUSY mixing parameters s_{13}, s_{23}

Our strategy



Our strategy



$S_{J/\psi K_S}$-|ε_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.

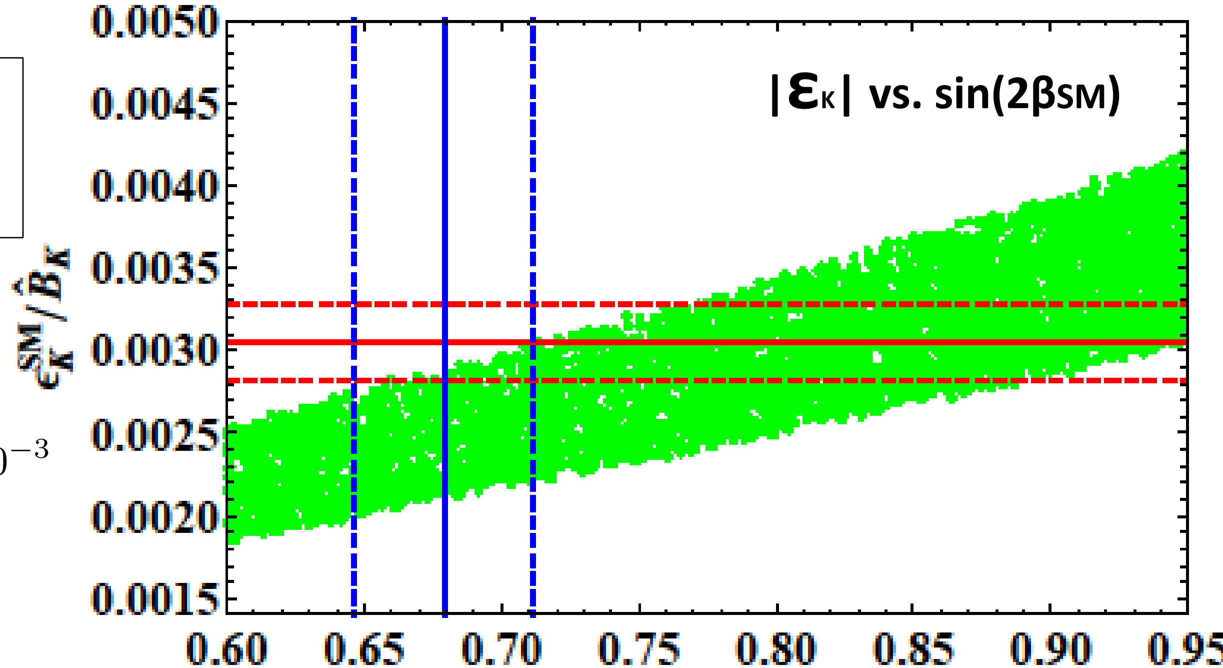
SM $|\varepsilon_K| \propto \hat{B}_K |V_{cb}|^4 \sin(2\beta_{SM})$ $S_{J/\psi K_S} = \sin(2\beta_{exp}) = \sin(2\beta_{SM})$

B_K : Lattice calculation

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

[JM.Gerard, 2011]

$|\epsilon_K^{exp}| = (2.228 \pm 0.011) \times 10^{-3}$



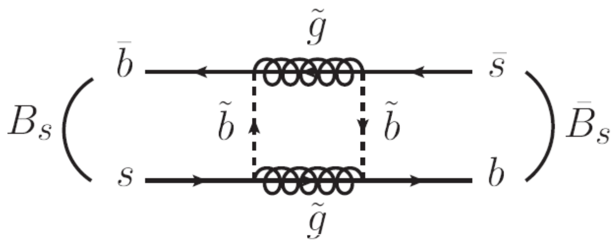
$S_{J/\psi K_S} = 0.679 \pm 0.02$ 90%C.L. sin(2βSM)

- 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.

Constraints

K-K̄, B-B̄ , Bs-B̄s mixing: $|\epsilon_K|$ ΔM_d ΔM_s

$$M_{12}^q = \langle B_q | H_{\rm eff} | \bar{B}_q \rangle = M_{12}^{q,{\rm SM}} + M_{12}^{q,{\rm SUSY}}$$



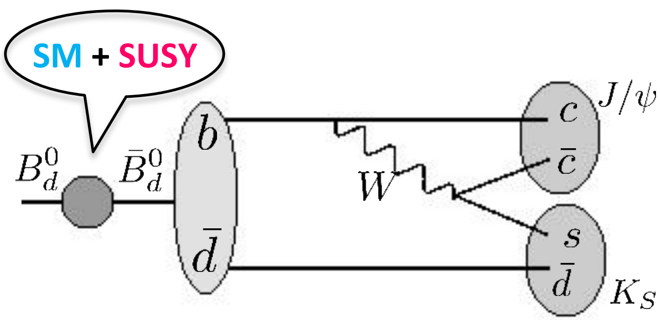
$$\Delta M_d = 2\left|M_{12}^d\right| \qquad \epsilon_K \propto {\rm Im}(M_{12}^K)$$

$$|\epsilon_K| \propto s_{13}s_{23} \qquad \Delta M_d \propto s_{13} \qquad \Delta M_s \propto s_{23}$$

Time dependent CP asymmetry : $S_{J/\psi K_S}$ $S_{J/\psi\phi}$

$$S_{J/\psi K_S} \rightarrow \sin(2\beta_{\rm SM} + {\rm Arg}(1 + \left|\frac{M_{12}^{\rm SM}}{M_{12}^{\rm SUSY}}\right| e^{2i\sigma}))$$

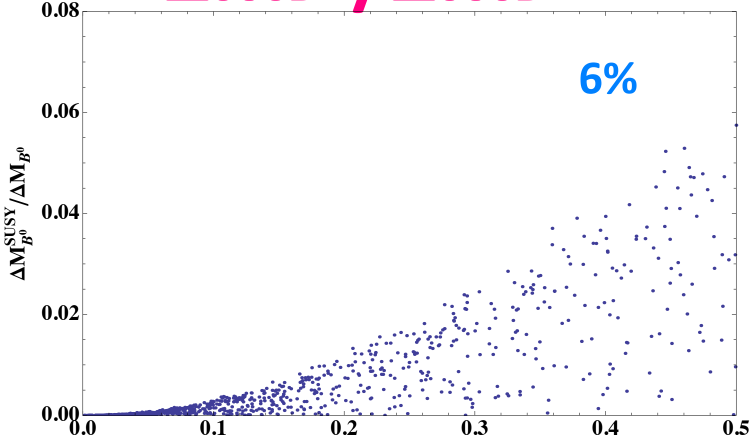
$$S_{J/\psi\phi} \rightarrow \sin(-2\beta_{s,{\rm SM}} + {\rm Arg}(1 + \left|\frac{M_{s,12}^{\rm SM}}{M_{s,12}^{\rm SUSY}}\right| e^{2i\sigma_s}))$$



$$S_{J/\psi K_S} \propto s_{13} \qquad S_{J/\psi\phi} \propto s_{23}$$

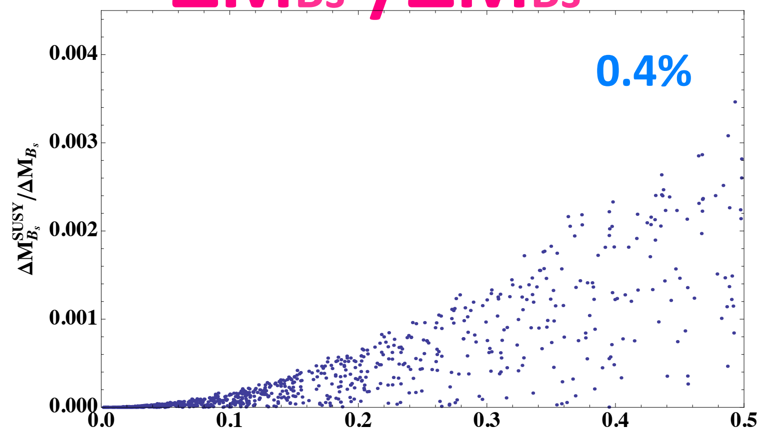
We scan s_{ij} randomly in the region of 0 ～ 0.5 with taking $|s_{ij}^L| = |s_{ij}^R|$

$\Delta M_B^{SUSY} / \Delta M_B^{SUSY+SM}$



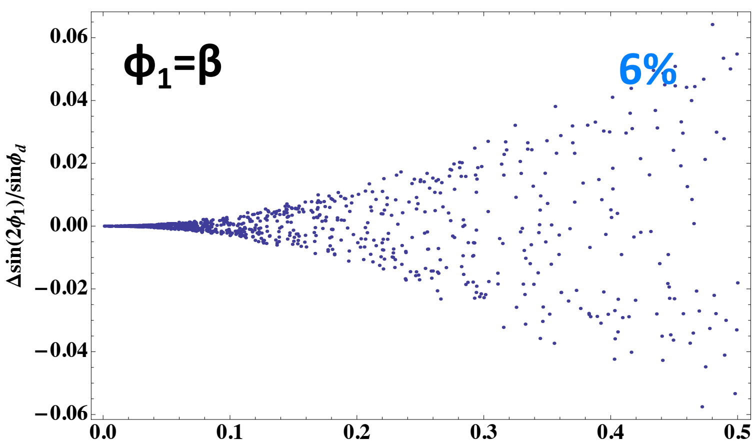
S_{13}

$\Delta M_{Bs}^{SUSY} / \Delta M_{Bs}^{SUSY+SM}$



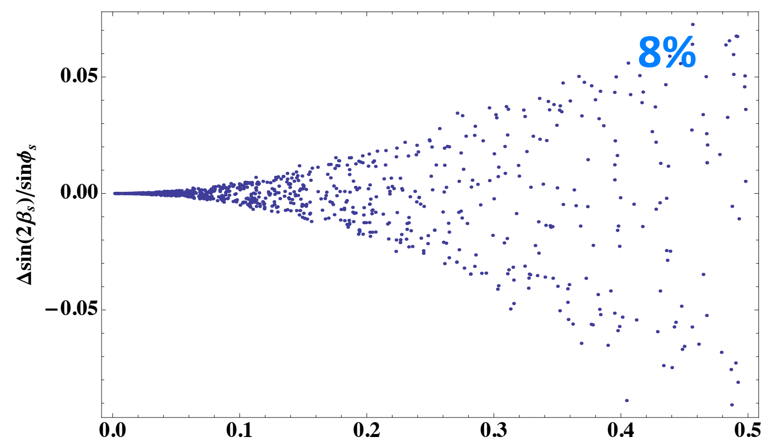
S_{23}

$\mathrm{Sin}(2\Phi_1)^{SUSY} / \mathrm{Sin}(2\Phi_1)^{SUSY+SM}$



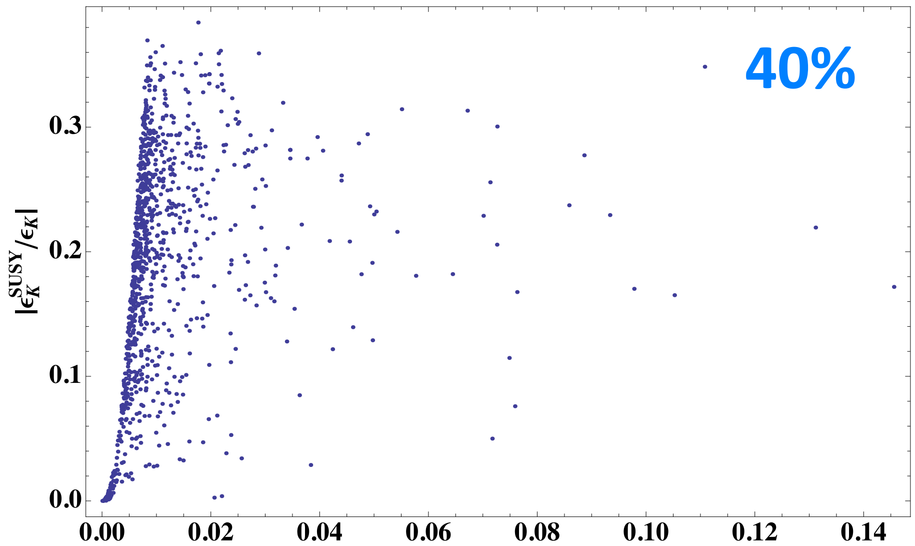
S_{13}

$\mathrm{Sin}(2\Phi s)^{SUSY} / \mathrm{Sin}(2\Phi s)^{SUSY+SM}$



S_{23}

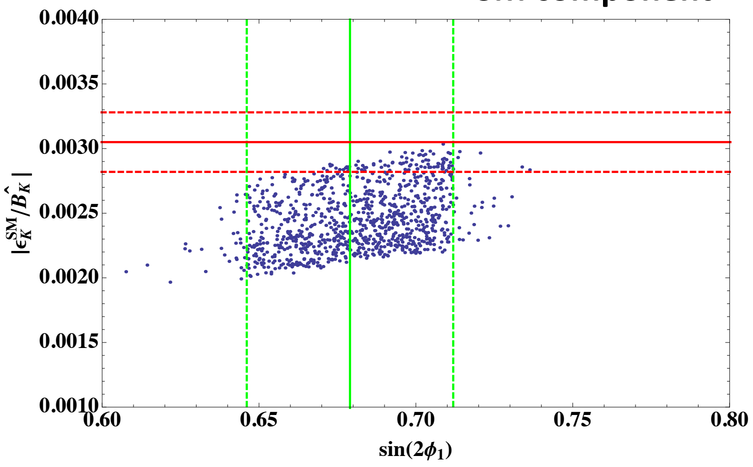
$\varepsilon_K^{SUSY} / \varepsilon_K^{SUSY+SM}$



$S_{13}S_{23}$

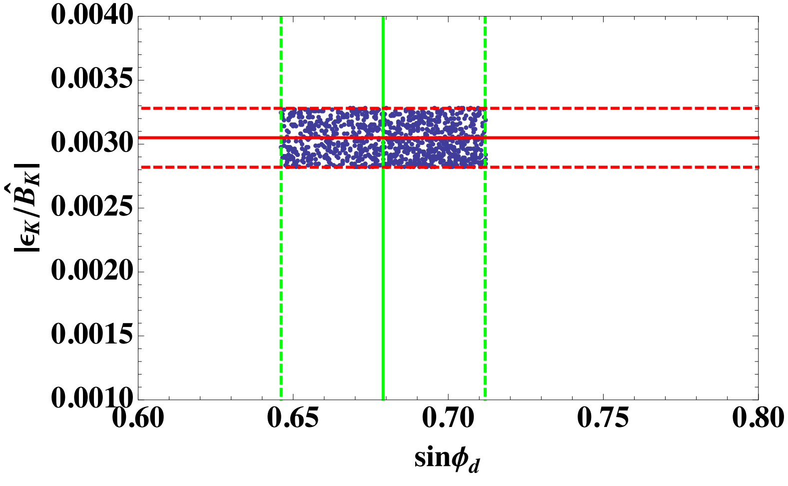
sensitive

SM component



Taking account of Gluino squark interaction

⇒



Our strategy

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

Constraints for SUSY mixing parameters s_{13}, s_{23}

Prediction

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

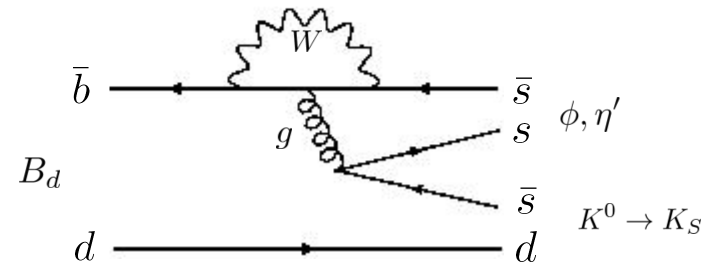
Time dependent CP asymmetry

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

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

S_f

$$\left(\lambda = \frac{q}{p}\frac{\bar{A}}{A}\right)$$



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

SM prediction

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

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

SUSY contribution

[S. Khalil ,E. Kou(2003), A.L. Kagan(2002), M.Endo,S.Mishima,M.Yamaguchi (2005)]

$$O_{8G} = \frac{g_s}{16\pi^2} m_b \bar{s}_i \sigma^{\mu\nu} P_R T^a_{ij} b_j G^a_{\mu\nu}$$

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

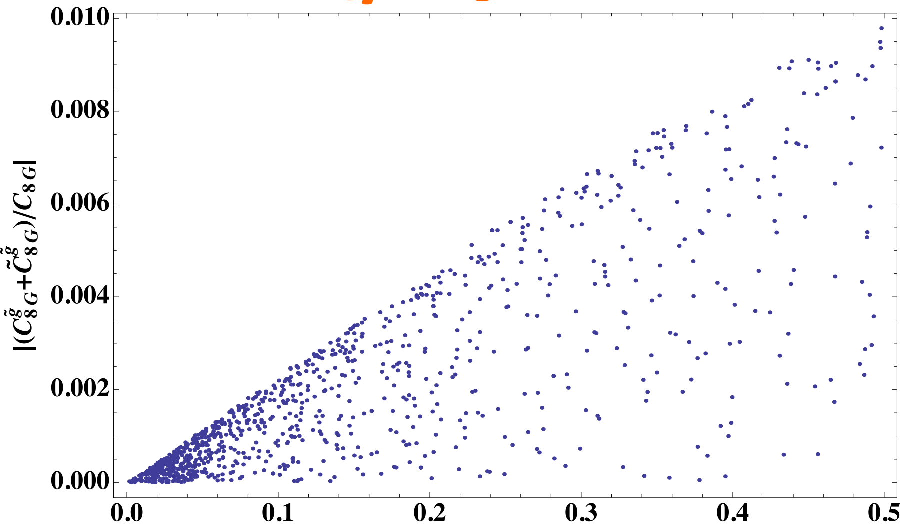
$\tilde{C} : C(L \Leftrightarrow R)$

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

- $C^{\tilde{g}}_{8G}$ is depend on S_{23}
- Difference of sign comes from parity of final state

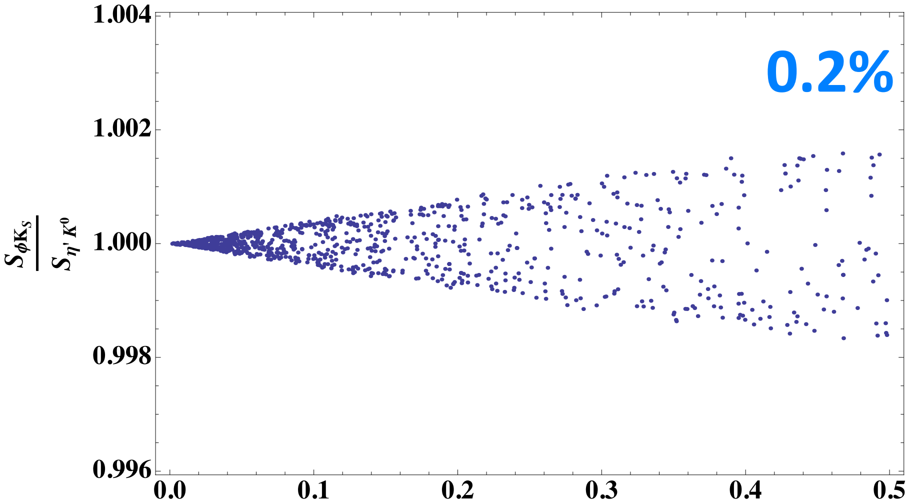
Time dependent CP asymmetry $S_{\phi K_S}, S_{\eta' K^0}$

$C_{8g}^{SUSY}/C_{8g}^{SM}$



S_{23}

$S_{\phi K}/S_{\eta' K}$



S_{23}

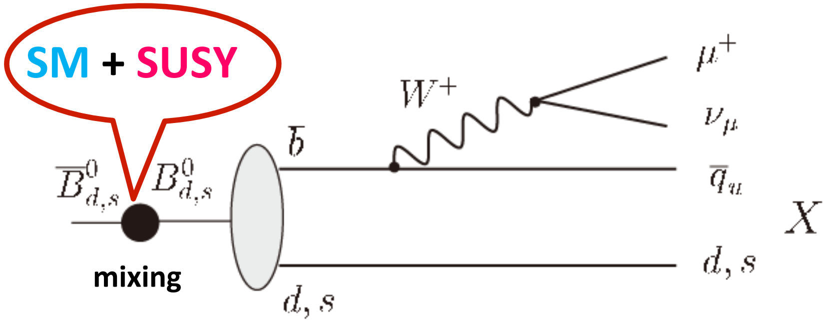
insensitive...

Semi-leptonic CP asymmetry a_{sl}^{d}, a_{sl}^{s}

- CP asymmetry in the semileptonic decay in $\overline{B}_q^0 \Longrightarrow B_q^0 \to \mu^+ X$

$$a_{sl}^{q} \equiv \frac{\Gamma\left(\overline{B}_q^0 \to \mu^+ X\right) - \Gamma\left(B_q^0 \to \mu^- X\right)}{\Gamma\left(\overline{B}_q^0 \to \mu^+ X\right) + \Gamma\left(B_q^0 \to \mu^- X\right)}$$

$$= \frac{1 - \left|\frac{p}{q}\right|^4}{1 + \left|\frac{p}{q}\right|^4} = -\mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)$$



SM predictions

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

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

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

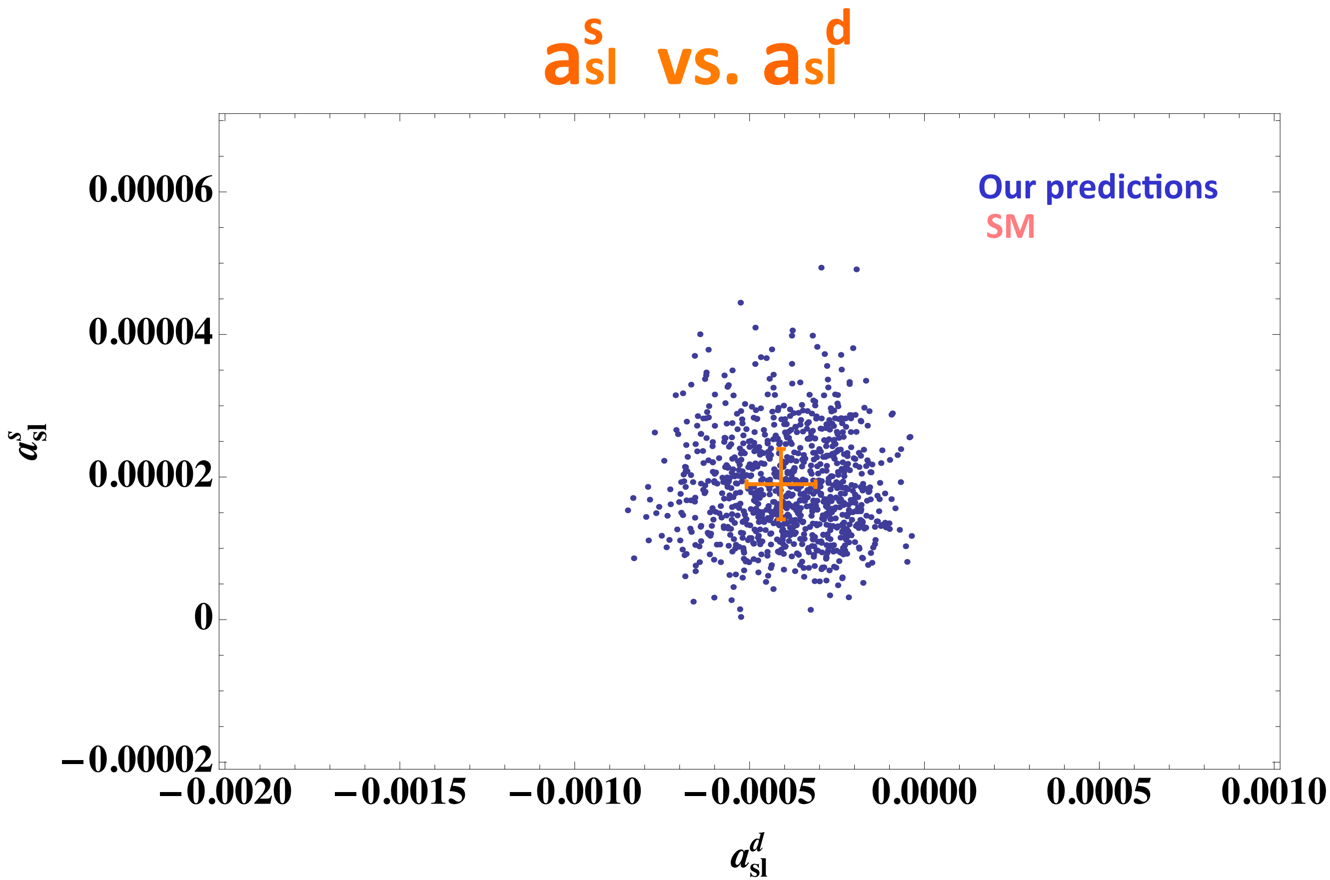
Experimental results [PDG 2012]

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

$$a_{sl}^{d} = (-0.3 \pm 2.1) \times 10^{-3}$$

- a_{sl}^{d} is depend on s_{13} , a_{sl}^{s} is depend on s_{23}

Semi-leptonic CP asymmetry a_{sl}^d, a_{sl}^s



$a_{sl}^d < 1\times10^{-3}$, $a_{sl}^s < 5 \times 10^{-5}$

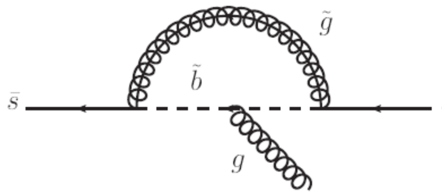
insensitive…

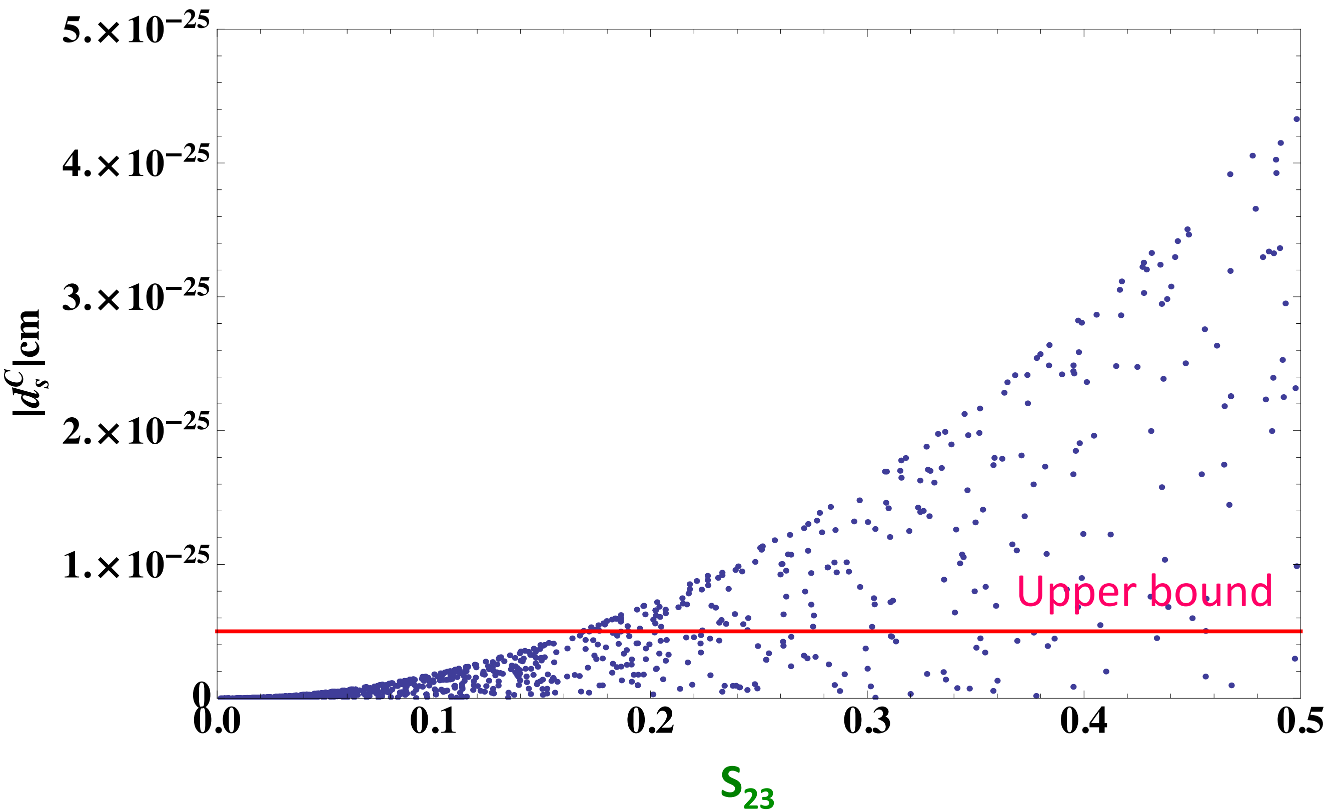
Chromo-EDM of strange quark

$$e|d_s^C| < 0.5 \times 10^{-25}\text{ecm}$$

[K.Fuyuto, J.Hisano and N.Nagata, 2013]

$$|d_s^C| \propto s_{23}^L c_{13}^L s_{23}^R c_{13}^R \sin(2\theta) e^{-i(\phi_{23}^L + \phi_{23}^R + \phi)}$$



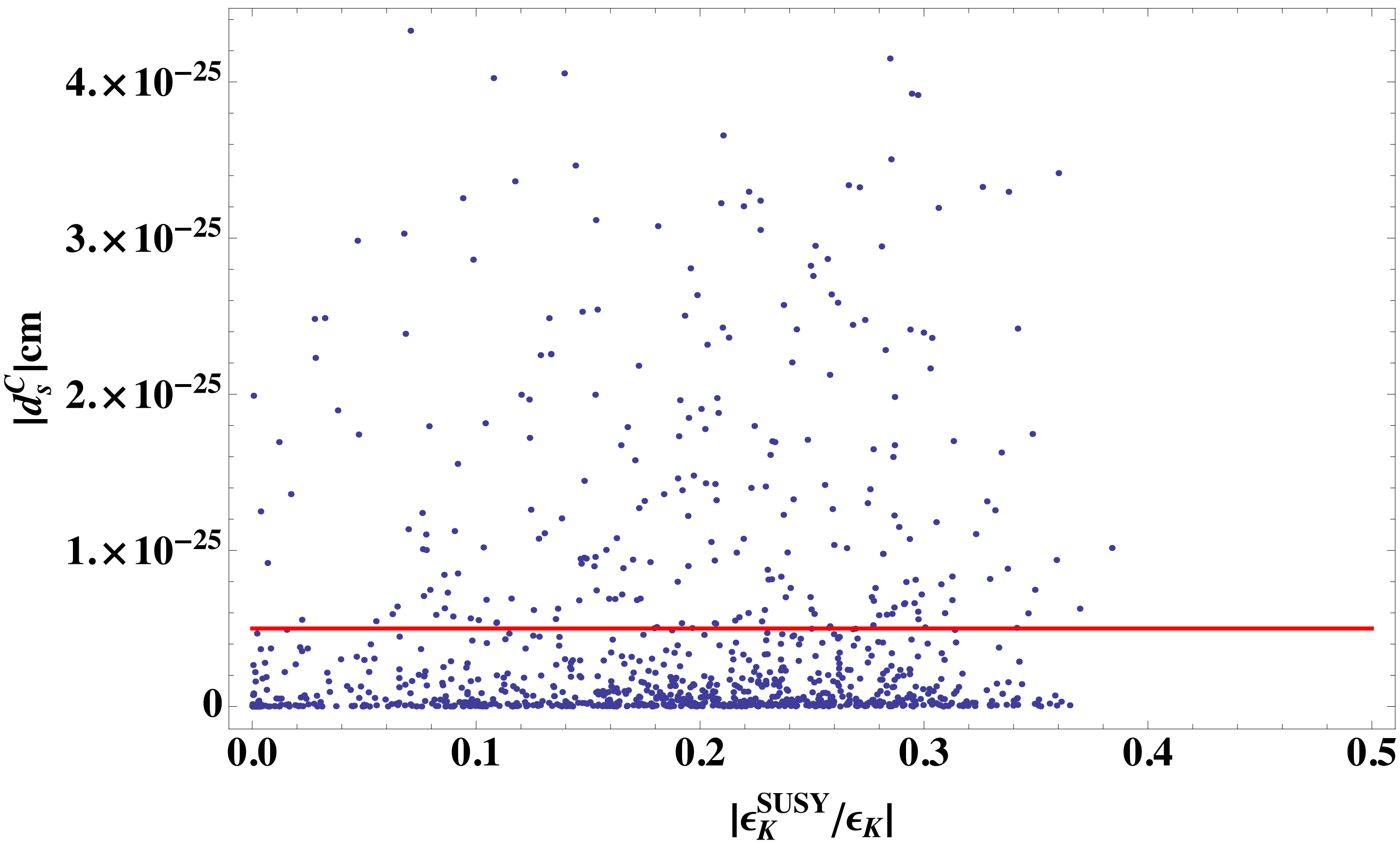


$|d_s^C| < 4 \times 10^{-25}$ cm

sensitive

Chromo-EDM of strange quark vs. ε_K

$$|d_s^C| \propto s_{23}^L c_{13}^L s_{23}^R c_{13}^R \sin(2\theta) e^{-i(\phi_{23}^L + \phi_{23}^R + \phi)}$$

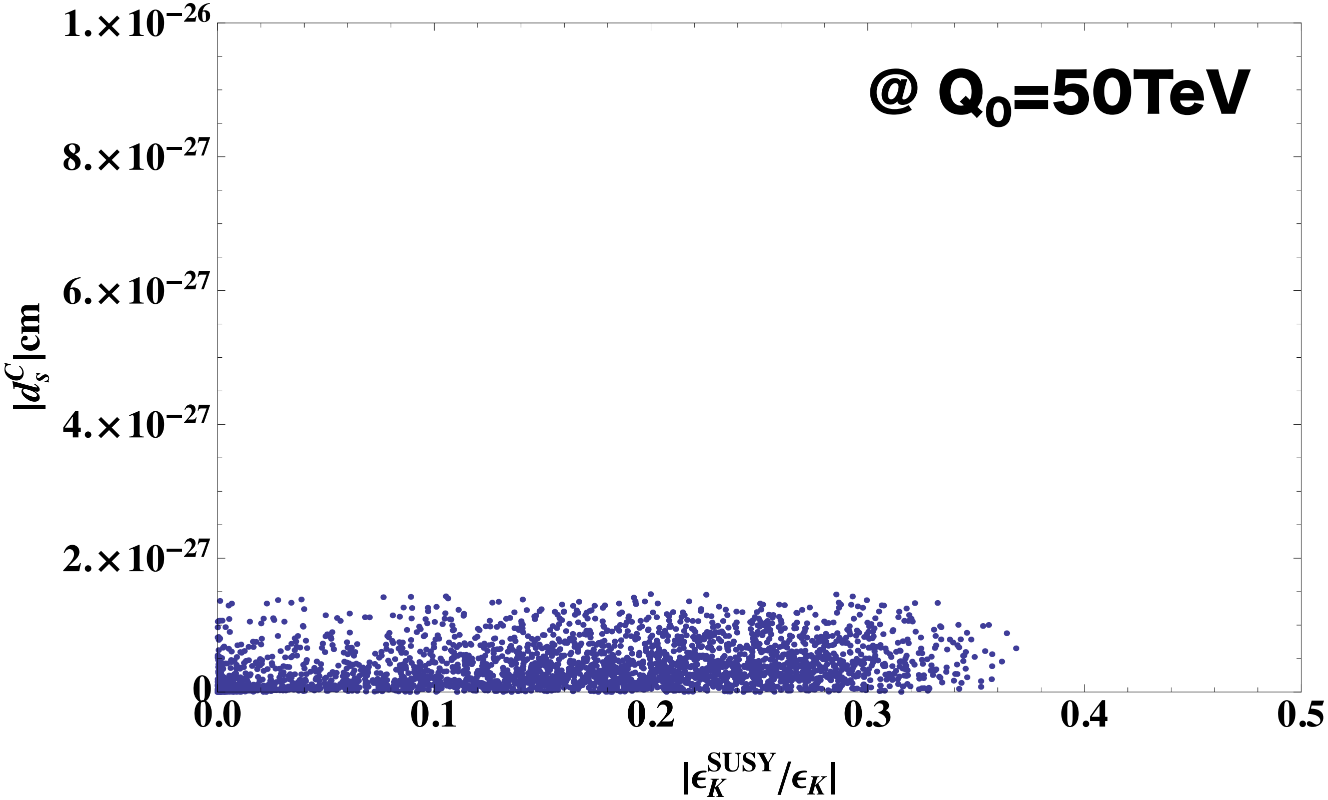


Chromo-EDM of strange quark vs. ε$_K$

$$|d_s^C| \propto s_{23}^L c_{13}^L s_{23}^R c_{13}^R \sin(2\theta) e^{-i(\phi_{23}^L + \phi_{23}^R + \phi)}$$

Q_0=10TeV ➡ Q_0=50TeV

$\theta = 0.35°$ $\theta = 0.05°$



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4. Summary

- We examined the sensitivity of High scale SUSY, in which squark spectrum is consistent with Higgs mass

	(a) $Q_0 = 10$ TeV	(b) $Q_0 = 50$ TeV
✓ $\lvert\epsilon_K\rvert$	40%	35%
$S_{J/\psi K_S}$	6%	0.1%
$S_{J/\psi\phi}$	8%	0.1%
ΔM_{B^0}	6%	0.1%
ΔM_{B_s}	0.4%	0.005%
$\lvert S_{\phi K_S}/S_{\eta' K^0}\rvert - 1$	0.2%	0.001%
$\mathrm{BR}(b \to s\gamma)$	0.3%	0.001%
$\lvert a_{sl}^d\rvert$	$\leq 1 \times 10^{-3}$	$\leq 8 \times 10^{-4}$
$\lvert a_{sl}^s\rvert$	$\leq 5 \times 10^{-5}$	$\leq 4 \times 10^{-5}$
✓ $\lvert d_s^C\rvert$	$\leq 4 \times 10^{-25}$cm	$\leq 1 \times 10^{-27}$cm

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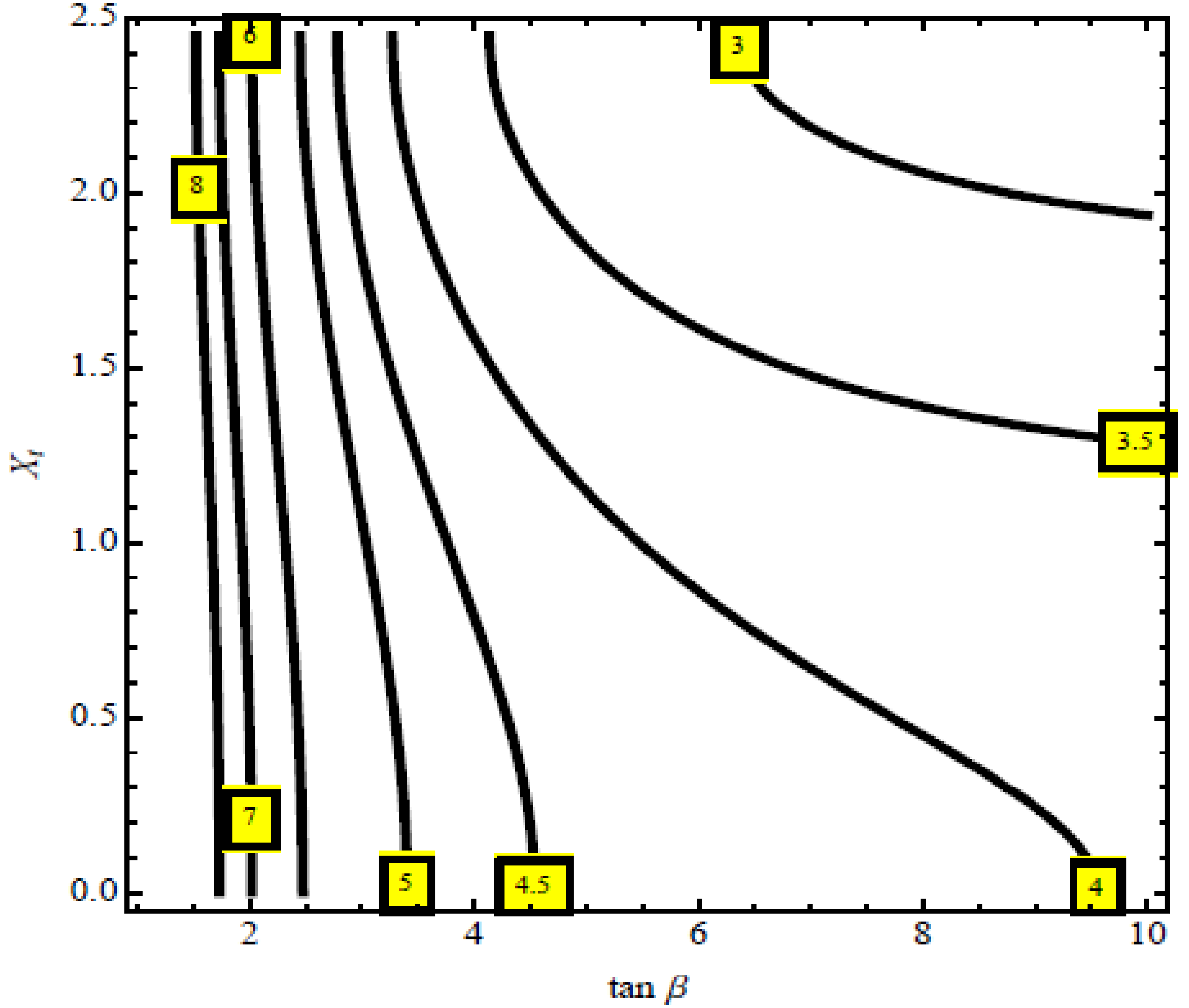
cEDM has sensitivity at 10-50 TeV

Backup

	Input at Λ and Q_0	Output at Q_0
Case (a)	at $\Lambda = 10^{17}$ GeV, $m_0 = 10$ TeV, $m_{1/2} = 6.2$ TeV, $A_0 = 25.803$ TeV; at $Q_0 = 10$ TeV, $\mu = 10$ TeV, $\tan\beta = 10$	$m_{\tilde{g}} = 12.8$ TeV, $m_{\tilde{W}} = 5.2$ TeV, $m_{\tilde{B}} = 2.9$ TeV $m_{\tilde{b}_L} = m_{\tilde{t}_L} = 12.2$ TeV $m_{\tilde{b}_R} = 14.1$ TeV, $m_{\tilde{t}_R} = 8.4$ TeV $m_{\tilde{s}_L,\tilde{d}_L} = m_{\tilde{c}_L,\tilde{u}_L} = 15.1$ TeV $m_{\tilde{s}_R,\tilde{d}_R} \simeq m_{\tilde{c}_R,\tilde{u}_R} = 14.6$ TeV, $m_{\mathcal{H}} = 13.7$ TeV $A_t = -1.2$ TeV, $A_b = 5.1$ TeV, $X_t = -0.22$ $\lambda_H = 0.126$, $\theta = 0.35°$
Case (b)	at $\Lambda = 10^{16}$ GeV, $m_0 = 50$ TeV, $m_{1/2} = 63.5$ TeV, $A_0 = 109.993$ TeV; at $Q_0 = 50$ TeV, $\mu = 50$ TeV, $\tan\beta = 4$	$m_{\tilde{g}} = 115.6$ TeV, $m_{\tilde{W}} = 55.4$ TeV, $m_{\tilde{B}} = 33.45$ TeV $m_{\tilde{b}_L} = m_{\tilde{t}_L} = 100.9$ TeV $m_{\tilde{b}_R} = 104.0$ TeV, $m_{\tilde{t}_R} = 83.2$ TeV $m_{\tilde{s}_L,\tilde{d}_L} = m_{\tilde{c}_L,\tilde{u}_L} = 110.7$ TeV, $m_{\tilde{s}_R,\tilde{d}_R} = 110.7$ TeV $m_{\tilde{c}_R,\tilde{u}_R} = 105.0$ TeV, $m_{\mathcal{H}} = 83.1$ TeV $A_t = -20.2$ TeV, $A_b = 4.7$ TeV, $X_t = -0.65$ $\lambda_H = 0.1007$, $\theta = 0.05°$

Table 1: Input parameters at Λ and obtained the SUSY spectra in the cases of (a) and (b).

$$\overline{m}_t(m_t) = 163.5 \pm 2 \text{ GeV}$$



[Delgado, Garcia, Quiros, arXiv:1312.3235]

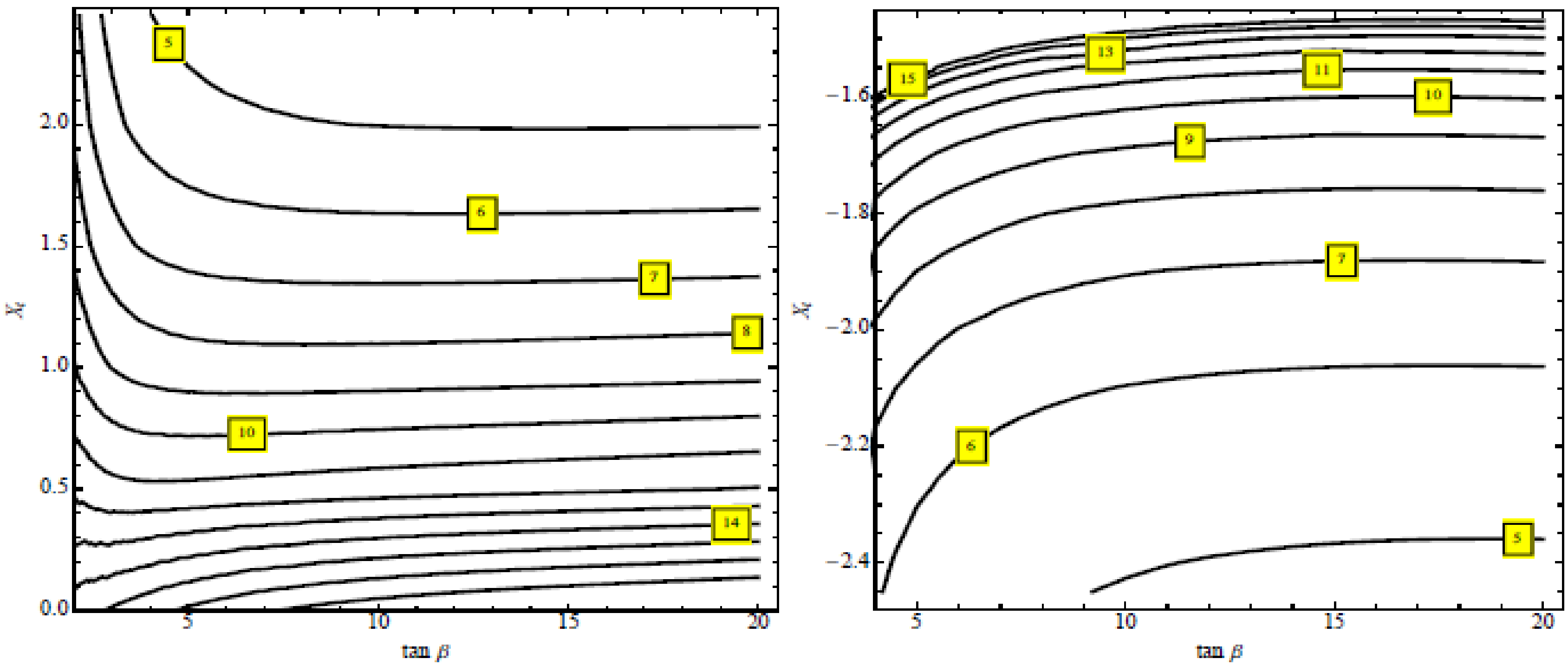
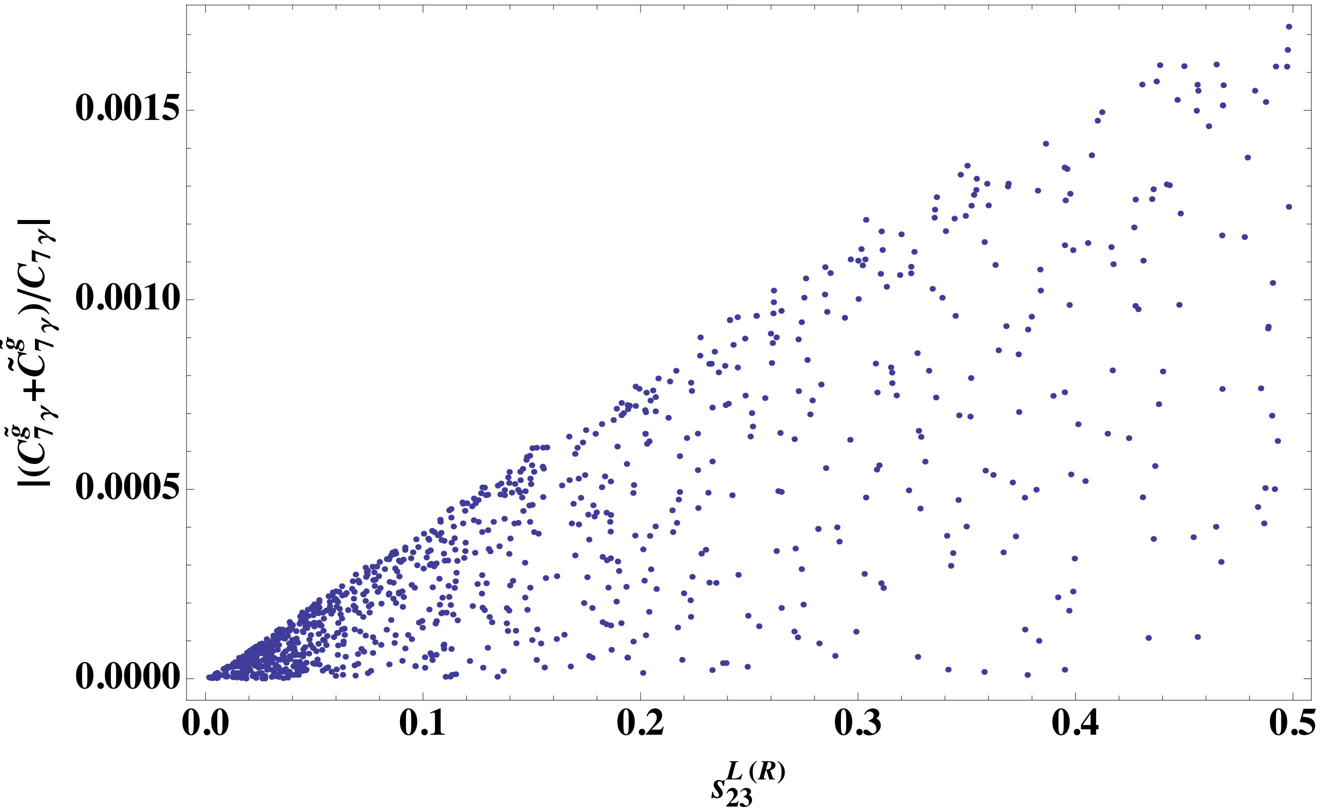


Figure 4: *Contour lines of constant* $\log_{10}[\mathcal{M}/\text{GeV}]$ *in the* $(\tan\beta, X_t)$ *plane for* $X_t \geq 0$ *(left panel) and* $X_t < 0$ *(right panel).*

[Delgado, Garcia, Quiros, arXiv:1312.3235]

$$C_{7\gamma}^{SUSY}/C_{7\gamma}^{SM}$$



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

$$|\epsilon_K^{exp}| = (2.228 \pm 0.011) \times 10^{-3}$$

$$\Delta M_s = (116.942 \pm 0.1564) \times 10^{-13}\text{GeV}$$

$$\Delta M_d = (3.337 \pm 0.033) \times 10^{-13}\text{GeV}$$

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

$$S_{J/\psi K_S} = 0.679 \pm 0.020$$

$S_{J/\psi\phi}$ $\phi_s = 0.07 \pm 0.09 \pm 0.01$

Complementarity of Belle II and LHCb

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\|V_{us}\|$ $[K \to \pi \ell \nu]$	**	0.1%	K-factory
$\|V_{cb}\|$ $[B \to X_c \ell \nu]$	**	1%	Belle II
$\|V_{ub}\|$ $[B_d \to \pi \ell \nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K_S^0]$	***	$8 \cdot 10^{-3}$	Belle II/LHCb
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K_S^0\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A_{SL}^d	***	0.001	LHCb
A_{SL}^s	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
zero of $A_{FB}(B \to K^*\mu\mu)$	**	0.05	LHCb
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
$\mathcal{B}(B \to s\gamma)$		4%	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$		$0.25 \cdot 10^{-6}$	Belle II (with 5 ab^{-1})

[A.Ishikawa talk (KEK-TH2013)]

Type	Observable	Current precision	LHCb 2018	**Upgrade** ($50\,\text{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s$ ($B_s^0 \to J/\psi\,\phi$)	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\, f_0(980)$)	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\text{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\text{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\text{eff}}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\text{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\text{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\, A_{\text{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_{\text{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\text{GeV}^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [16]	8 %	2.5 %	$\sim 10\,\%$
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	$\sim 100\,\%$	$\sim 35\,\%$	$\sim 5\,\%$
Unitarity triangle angles	γ ($B \to D^{(*)}K^{(*)}$)	$\sim$ 10–12° [19, 20]	4°	0.9°	negligible
	γ ($B_s^0 \to D_s K$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\, K_S^0$)	0.8° [18]	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–

Table 1: Statistical sensitivities of the LHCb upgrade to key observables. For each observable the current sensitivity is compared to that which will be achieved by LHCb before the upgrade, and that which will be achieved with $50\,\text{fb}^{-1}$ by the upgraded experiment. Systematic uncertainties are expected to be non-negligible for the most precisely measured quantities.

The cEDM of the strange quark from gluino contribution is given by [65]

$$d_s^C(Q_0) = -2\sqrt{4\pi\alpha_s(m_{\tilde{g}})}\mathrm{Im}[A_s^{g22}(Q_0)], \tag{64}$$

where

$$\begin{aligned} A_s^{g22}(Q_0) = -\frac{\alpha_s(m_{\tilde{g}})}{4\pi}\frac{1}{3}\Bigg[\frac{1}{2m_{\tilde{d}_3}^2}\Bigg\{\Big(m_s(\lambda_{GLL}^{(d)})_3^{22} + m_s(\lambda_{GRR}^{(d)})_3^{22}\Big)\Big(9F_1(x_{\tilde{g}}^3) + F_2(x_{\tilde{g}}^3)\Big) \\ + m_{\tilde{g}}(\lambda_{GLR}^{(d)})_3^{22}\Big(9F_3(x_{\tilde{g}}^3) + F_4(x_{\tilde{g}}^3)\Big)\Bigg\} \end{aligned} \tag{65}$$

$$+ \frac{1}{2m_{\tilde{d}_6}^2}\Bigg\{\Big(m_s(\lambda_{GLL}^{(d)})_6^{22} + m_s(\lambda_{GRR}^{(d)})_6^{22}\Big)\Big(9F_1(x_{\tilde{g}}^6) + F_2(x_{\tilde{g}}^6)\Big) + m_{\tilde{g}}(\lambda_{GLR}^{(d)})_6^{22}\Big(9F_3(x_{\tilde{g}}^6) + F_4(x_{\tilde{g}}^6)\Big)\Bigg\}\Bigg].$$

Including the QCD correction, we get

$$d_s^C(2\mathrm{GeV}) = d_s^C(Q_0)\left(\frac{\alpha_s(Q_0)}{\alpha_s(m_{\tilde{g}})}\right)^{\frac{14}{15}}\left(\frac{\alpha_s(m_{\tilde{g}})}{\alpha_s(m_t)}\right)^{\frac{14}{21}}\left(\frac{\alpha_s(m_t)}{\alpha_s(m_b)}\right)^{\frac{14}{23}}\left(\frac{\alpha_s(m_b)}{\alpha_s(2\mathrm{GeV})}\right)^{\frac{14}{25}}. \tag{66}$$

Factorization relation

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

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

[R. Harnik, D. T. Larson, H. Murayama and A. Pierce (2004)]