Implications of dimuon charged asymmetry at D0 on general SUSY models

National Central University (Dec. 10, 2010)

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Prelude on D0 data

- Semileptonic charge asymmetry

$$A_{\rm sl}^q \equiv \frac{\Gamma(\overline{B_q^0}(t) \to \mu^+ X) - \Gamma(B_q^0(t) \to \mu^- X)}{\Gamma(\overline{B_q^0}(t) \to \mu^+ X) + \Gamma(B_q^0(t) \to \mu^- X)},$$

for $q = d, s$.

- D0 result on dilepton charge asymmetry :

$$\begin{aligned} A_{\rm SL} &\equiv \frac{\Gamma(b\bar{b} \to \mu^+\mu^+ X) - \Gamma(b\bar{b} \to \mu^-\mu^- X)}{\Gamma(b\bar{b} \to \mu^+\mu^+ X) + \Gamma(b\bar{b} \to \mu^-\mu^- X)} \\ &\simeq 0.506 A_{\rm SL}^d + 0.494 A_{\rm SL}^s \\ &= -0.957 \pm 0.251 \pm 0.146\% \end{aligned}$$

Prelude on D0 data II

- BaBar, Belle and CLEO : $A_{\rm SL}^{d} = (-4.7 \pm 4.6) \times 10^{-4}$
- So one gets $A_{\rm SL}^{s} = -0.0146 \pm 0.0075$
- SM prediction: $\sim -2 \times 10^{-5}$

	SM prediction	Data
$A_{\rm SL}^{d}$	$(-4.8 \pm 1.0) \times 10^{-4}$	$(-4.7 \pm 4.6) \times 10^{-3}$
$A_{\rm SL}^{s}$	$(+2.06 \pm 0.57) \times 10^{-5}$	$(-1.46 \pm 0.75) \times 10^{-2}$
$A_{\rm SL}^{b}$	$(-2.3 \pm 0.5) \times 10^{-4}$	$(-9.57 \pm 2.51) \times 10^{-4}$

Can we understand such a large deviation (in SUSY models) ?

Contents

- Status of the SM and CKM matrix
- SUSY FCNC/CP Problems
- Earlier Literatures
- $s \to d$ transition: ϵ_K and $\epsilon^{'}/\epsilon_K$
- $b \to d$ transition: $B_d - \overline{B_d}$ mixing and $B \to X_d \gamma$
- $b \to s$ transition: $B_s - \overline{B_s}$ mixing, $B \to X_s \gamma$ and $B_d \to \phi K_s$ CP asymmetry
  - $B_s - \overline{B_s}$ mixing in SUSY models
  - Implications on SUSY (flavor) models
- Concluding Remarks

My talk is based on the following papers

- "Fully supersymmetric CP violations in the kaon system." Seungwon Baek, J.H. Jang, P. Ko, Jae-hyeon Park, Phys.Rev.D62:117701,2000.
- "Gluino squark contributions to CP violations in the kaon system." Seungwon Baek, J.H. Jang, P. Ko, Jae-hyeon Park, Nucl.Phys.B609:442-468,2001.
- "$B^0 - \overline{B^0}$ mixing, $B \to J/\psi K_s$ and $B \to X_d \gamma$ in general MSSM." P. Ko, Jae-hyeon Park, G. Kramer, Eur.Phys.J.C25:615-622,2002.
- "$B_d \to \phi K_s$ CP asymmetries as an important probe of supersymmetry." G.L. Kane, P. Ko, Hai-bin Wang, C. Kolda, Jae-hyeon Park, Lian-Tao Wang. Phys.Rev.Lett.90:141803,2003.

- “$B_d \to \phi K_s$ and supersymmetry.” G.L. Kane, P. Ko, Hai-bin Wang,, C. Kolda, Jae-hyeon Park, Lian-Tao Wang, Phys.Rev.D70:035015,2004.
- “Implications of the measurements of $B_s - \overline{B_s}$ mixing on SUSY models.” P. Ko, Jae-hyeon Park, Phys.Rev.D80:035019,2009.
- “Addendum to: Implications of the measurements of $B_s - \overline{B_s}$ mixing on SUSY models.” P. Ko, Jae-hyeon Park.

CKM matrix

- Mixing matrix connecting weak interaction eigenstates and mass eigenstates of quarks.

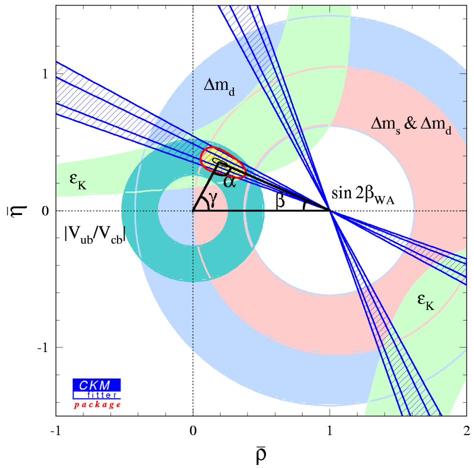
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- CKM matrix is hierarchical and has one CP phase.

$$V = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

- Unitarity condition, $V^\dagger V = V V^\dagger = \mathbf{1}$, yields unitarity triangles (UT).

Unitarity triangle on the (ρ, η) plane



- SM fit of (ρ, η)
- In the presence of new physics, constraints on (ρ, η) coming from
  one loop processes such as $\epsilon_K, \Delta m_d$, and Δm_s, may be weaker
- Even if the shape of the UT is the same as this SM fit, there are processes with large deviations within SUSY models

SUSY FCNC/CP problem

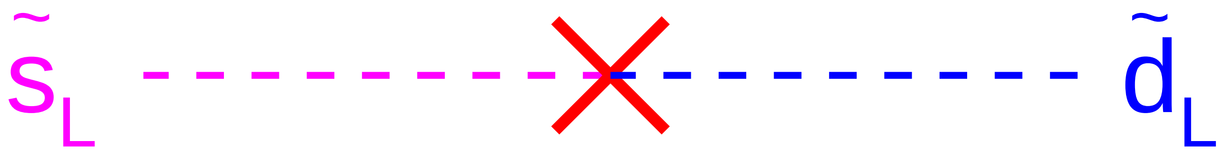
- Supersymmetry is symmetry between a fermion and a boson, which has many nice motivations such as resolution of gauge hierarchy problem, gauge coupling unification, and dark matter. But SUSY must be broken if is exists.
- Supersymmetrizing SM doubles the particle spectrum, introducing more than 100 new parameters in the soft SUSY breaking sector.
- Soft SUSY breaking parameters are complex and flavor violating, and a generic supersymmetric standard model results in huge FCNC and CP violation.
- There must be some mechanism which controls FCNC and CP. This may be due to the SUSY breaking mediation mechanism and/or some flavor symmetry.

Digress-I

- In particular, quark and squark mass matrices are not diagonalized simultaneously in general
$\rightarrow$ Gluino mediated FCNC, which could easily dominate the SM amplitudes ($\sim$ EW strength)
$\rightarrow$ SUSY flavor problem
- Possible Solutions
  - Universality (at some scale)
  - Alignment using some flavor symmetries
  - Decoupling (Effective SUSY models): Cohen, Kaplan, Nelson
$\leftarrow$ Disfavored by muon $(g-2)$
- $A_{\rm SL}$ can tell something [Randall and Su, NPB (1999)]
- All the related observables should be considered altogether [Ko, Kramer, Park (2002)]

Digress-II

- Mass insertion approximation is a useful tool to present flavor violation in the sfermion sector. $(\delta^d_{12})_{LL}$: dimensionless transition strength from $\widetilde{s}_L$ to $\widetilde{d}_L$.



- We can do the same for $b_A \to d_B$ and $b_A \to s_B$ $(A, B = L, R$: chiralities of superpartners of squarks)
- If $\delta \sim O(1)$, large FCNC and CPV with strong couplings
- SUSY FCNC/CP problem δ's should be small $\lesssim 10^{-1} - 10^{-3}$ depending on $AB = LL, RR, LR, RL$

Digress-III

- Current CKMology says New Physics should be flavor/CP blind to a very good approximation $\rightarrow$ Better to have $\delta = 0$
- Even if we set δ's to zero by hand at one energy scale, it is regerated by RG evolution.
  $\rightarrow$ Cannot make it vanish at all scales
- Either we consider δ's as parameters at EW scale, or assume δ's vanish at some scale (messenger scale) where Soft SUSY breaking terms are generated
- mSUGRA makes an ad hoc assumption of universal scalar masses at M_{Planck} or M_{GUT} scale (δ's are zero), and the δ's are generated by RG evolution
- Can we do better than simply assuming it ?
- Yes (Gauge mediation, Anoamaly mediation, Dilaton dominated SUSY breaking ,....)

Basic Strategies

- Once again, “Flavor physics and CP violation” such as $B \to X_s\gamma$, $B_s \to \mu^+\mu^-$, ϵ_K..... in SUSY models depend strongly on Soft SUSY Breaking sector, which is not well understood yet
- Without complete understanding of SUSY breaking, we have to rely on
  - Mass Insertion Approximation (MIA) to include gluino-squark loop contribution,
    OR
  - Work in some well motivated specific scenarios mSUGRA, GMSB, Dilaton Dominated SB (string theory), AMSB, ... where gluino-squark loop contributions (δ’s) are under control, and study the implications on flavour physics

Implications for SUSY flavor models

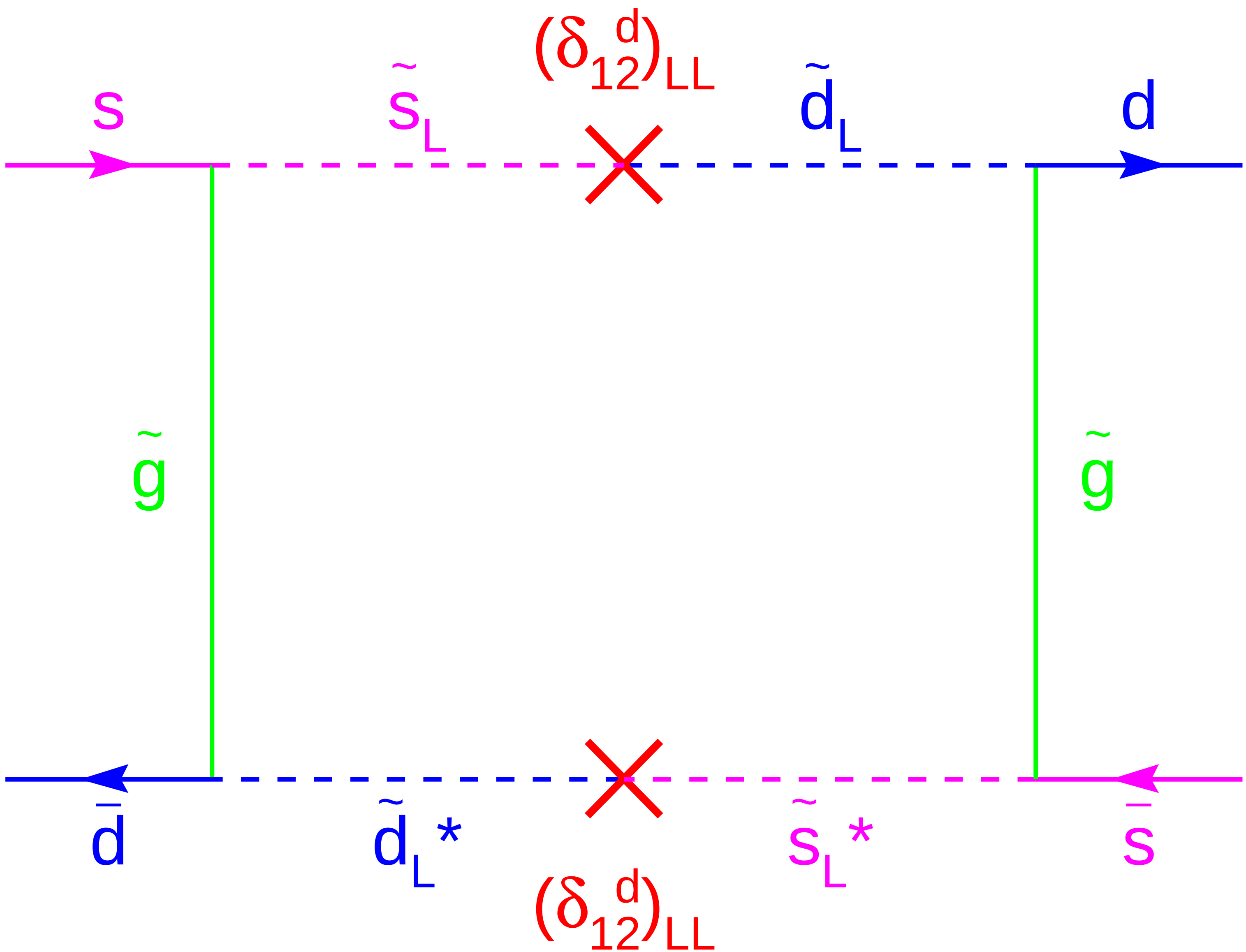
Model	$\lvert\delta^{23}_{d,LL}\rvert$	$\lvert\delta^{23}_{d,RR}\rvert$	$\tan\beta = 3$	$\tan\beta = 10$
LNS (A)	λ^2	λ^4	$\cdot$	$\surd$
NS ; CHM (A)	λ^2	1	$\times$	$\times$
NR (A)	λ^2	λ^8	$\cdot$	$\surd$
CHM (NA)	λ^2	$\lambda^{1/2}$	$\times$	$\times$
BHRR, PT (NA)	λ^2	λ^2	ϕ_s	$\surd$
HM (NA)	λ^3	λ^5	$\cdot$	$\cdot$
PS (NA)	λ^2	λ^4	$\cdot$	$\surd$
CKN (D)	λ^2	$LL \gg RR$	$\cdot$	$\surd$

Status of some models analyzed Randall and Su, for the two different values of $\tan\beta$. (A=Abelian, NA=Nonabelian, D=Decoupling) ($\cdot$) incompatible with ϕ_s but safe otherwise; (ϕ_s) compatible with ϕ_s and safe; ($\surd$) currently okay but dangerous; ($\times$) disfavored.

$s \to d$ transition (12 Mixing) ϵ_K and Re$(\epsilon^{'}/\epsilon_K)$

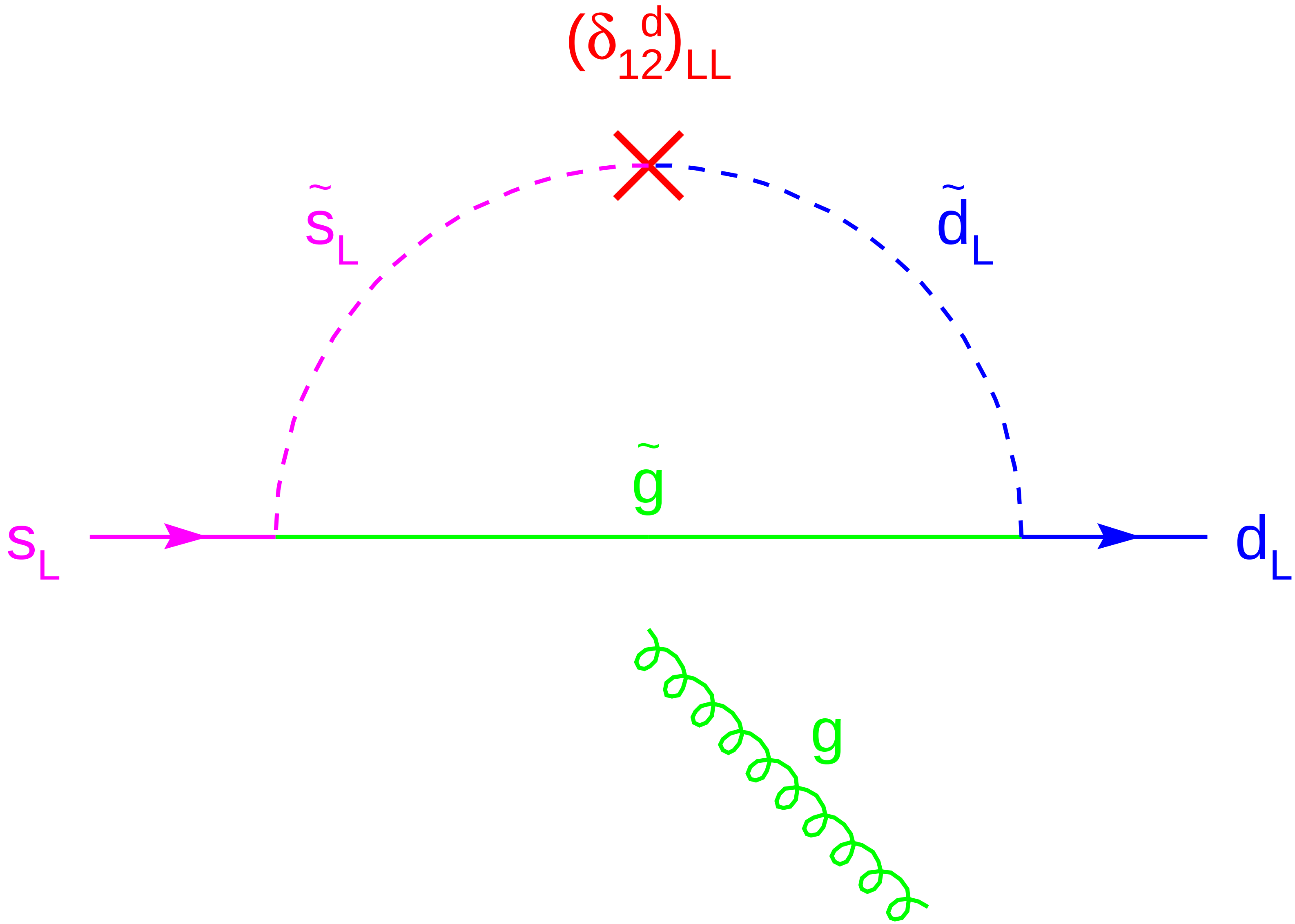
SUSY contributions to ϵ_K

- Diagrams:



SUSY contributions to ϵ'/ϵ

- Diagram :



Fully Supersymmetric CPV in the kaon system

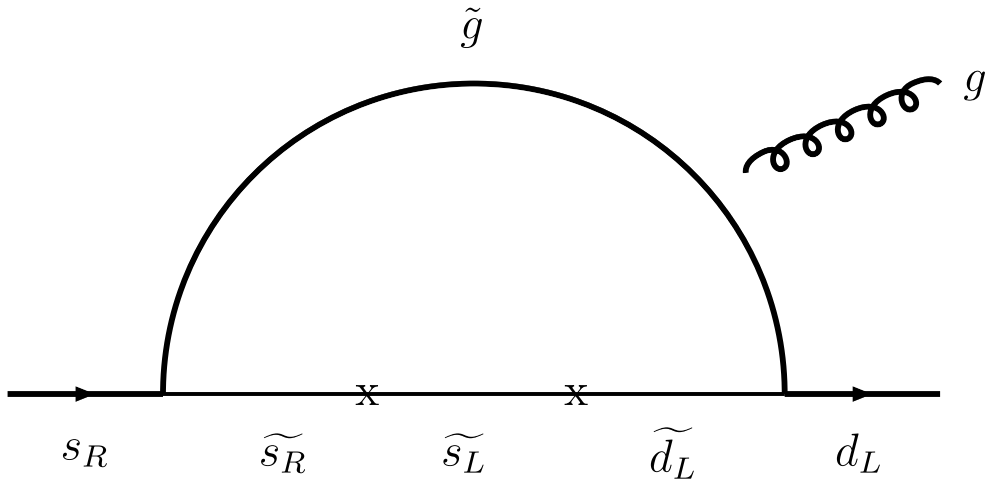
- CP violating parameters in the kaon system
  - $\epsilon_K = e^{i\pi/4}\,(2.280 \pm 0.013) \times 10^{-3}$: CP violation in the $K^0 - \overline{K^0}$ mixing ($\Delta S = 1$)
  - $\mathrm{Re}(\epsilon'/\epsilon_K) = (18 \pm 4) \times 10^{-4}$: CP violation in the decay amplitude ($\Delta S = 1$)
- These two can be accommodated by the KM phase in the Glashow-Salam-Weinberg's standard model (SM)
- SM prediction for $\mathrm{Re}(\epsilon'/\epsilon_K)$:
  - Buras et al. (before 1999) : 5×10^{-4}
  - Bertolini et al. : $5 - 30 \times 10^{-4}$
  - Large Hadronic Uncertainties $\rightarrow$ Need Lattice QCD Calculations after all

Fully SUSY CPV in K

- Can SUSY explain such a large $\mathrm{Re}(\epsilon'/\epsilon_K)$?
  Answer : The folklore was " No " again before 1999,
  Until Masiero and Murayama showed that it is possible
- P. Ko et al.: Both ϵ_K and $\mathrm{Re}(\epsilon'/\epsilon_K)$ can be explained in terms of a single SUSY parameter $(\delta^d_{12})_{LL}$, even if the KM phase is zero, without conflict with the e/n EDM's
  $\rightarrow$ Fully SUSY CP violation is possible in the MSSM with a single CPV parameter $(\delta_{LL})_{12}$
- Key Point : Double mass insertion can be important at large $|\mu \tan\beta| \sim O(5-10)$ TeV
- Completely different from Masiero and Murayama's mechanism, and no problem with neutron EDM in our model

Double Mass insertion

- Double mass insertion can be important in the large $\tan\beta$ region
- Diagrams:



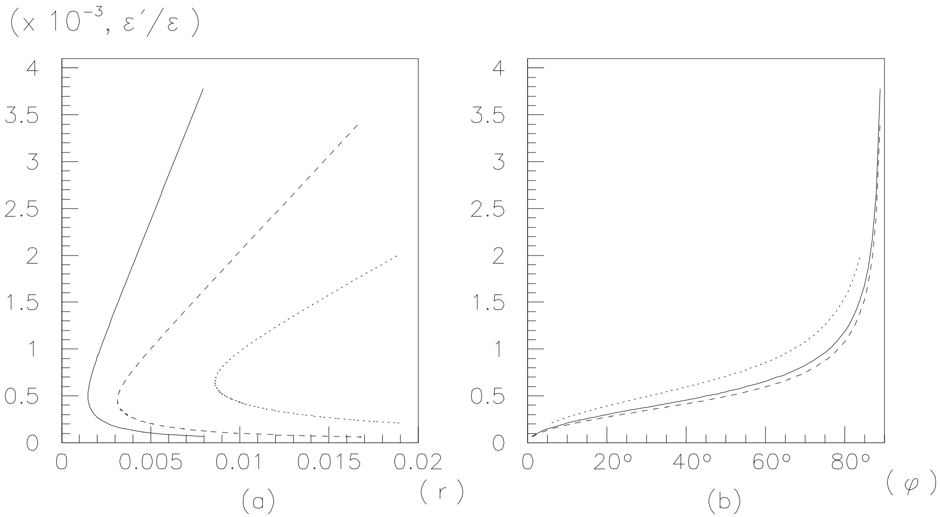
(Baek, Jang, Ko, Park, PRD(2000))

Fully SUSY CPV in K-Cont'd

- $|(\delta^d_{12})_{LL}| \sim O(10^{-3} - 10^{-2})$ with the phase $\sim O(1)$ saturates ϵ_K
- This parameter can lead to a sizable $\mathrm{Re}(\epsilon'/\epsilon_K)$ through the $(\delta^d_{12})_{LL}$ insertion followed by the Flavor Preserving (FP) (LR) mass insertion

$$\propto (\delta^d_{22})_{LR} \equiv m_s(A^*_s - \mu \tan\beta)/\tilde{m}^2 \sim O(10^{-2}),$$

- This FP LR insertion is generically present in any SUSY models
- $(\delta^d_{12})^{\mathrm{ind}}_{LR} = (\delta^d_{12})_{LL}(\delta^d_{22})_{LR} \sim 10^{-5}$ with $O(1)$ phase
- The same mechanism can happen in $b \to s$ transitions



- Different predictions for $K \to \pi \nu \nu$ from the SM

$b \to d$ Transition (13 Mixing) $B_d - \overline{B_d}$ mixing, and $B_d \to X_d\gamma$

1-3 Mixing : $B_d - \overline{B_d}$ mixing, and $B_d \to X_d \gamma$

Ko, Kramer, Park, EJPC (2003)]

- Amp (tot) = Amp (SM) + Amp (SUSY: $\tilde{g}$-down squark) for $B^0 - \overline{B^0}$ mixing and $B_d \to X_d \gamma$
- Mass insertion approximation with $m_{\tilde{g}} = \widetilde{m} = 500$ GeV
- Scan over one of δ_{13}^d's as well as $\gamma(\phi_3)$ (KM angle)
- Constraints

$$\Delta m_d = (0.472 \pm 0.017)\ \mathrm{ps}^{-1}$$

$$\sin 2\beta_{J/\psi} = 0.79 \pm 0.10$$

$$B(B \to X_d \gamma) < 1 \times 10^{-5}$$

1-3 Mixing : Cont'd

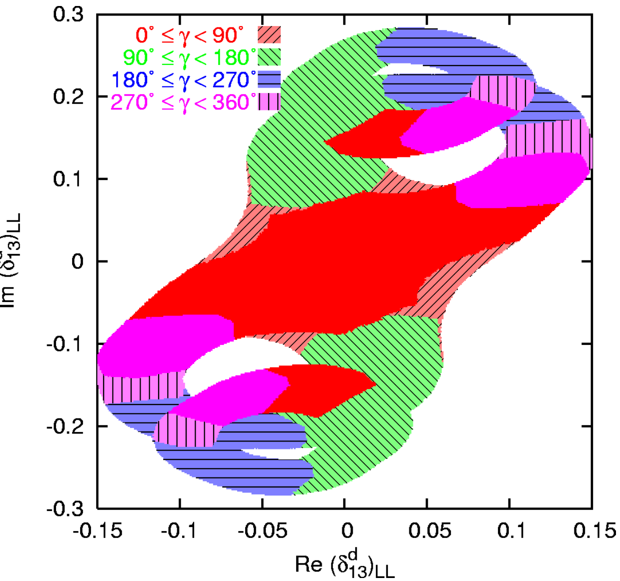
- Predictions

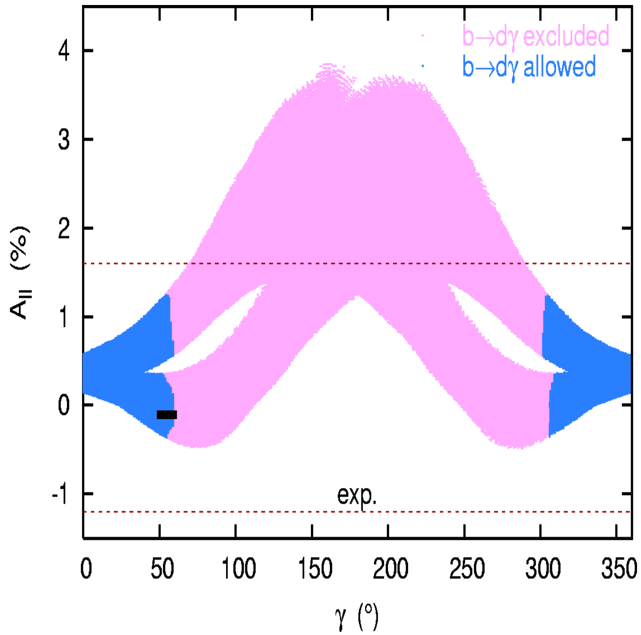
$$A_{ll} \equiv \frac{N(BB) - N(\bar{B}\bar{B})}{N(BB) + N(\bar{B}\bar{B})} \approx \mathrm{Im}\left(\frac{\Gamma_{12} \approx \Gamma_{12}^{\mathrm{SM}}}{M_{12}^{\mathrm{SM}} + M_{12}^{\mathrm{SUSY}}}\right)$$

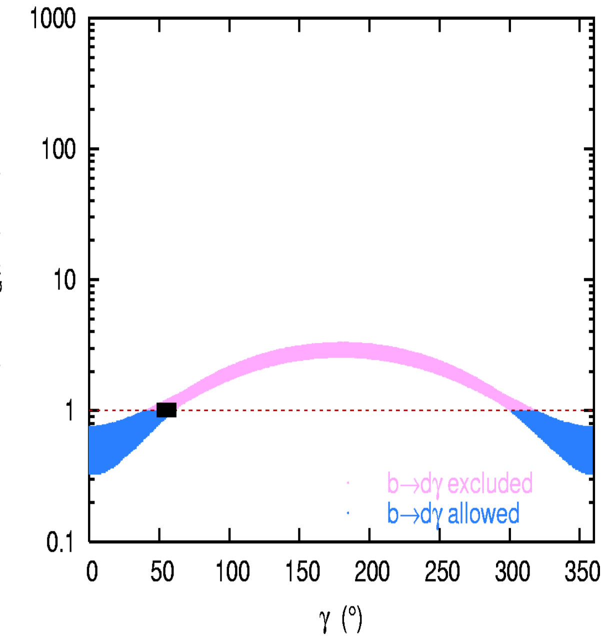
$$A_{\mathrm{CP}}^{b\to d\gamma} \equiv \frac{\Gamma(B \to X_d\,\gamma) - \Gamma(\overline{B} \to \overline{X_d}\,\gamma)}{\Gamma(B \to X_d\,\gamma) + \Gamma(\overline{B} \to \overline{X_d}\,\gamma)}$$

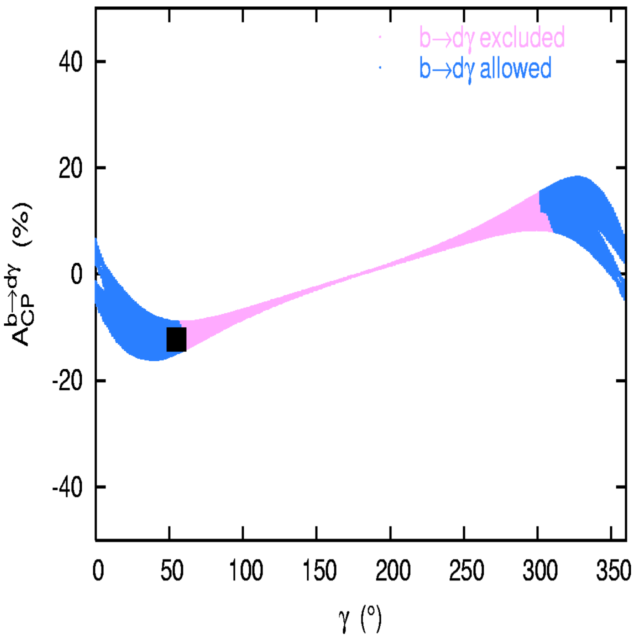
- Data : $A_{ll}^{\mathrm{exp}} = (-0.13 \pm 0.60 \pm 0.56)\%$ (BELLE)
- Consider two cases:
  - Single $(\delta_{13}^d)_{LL}$ insertion
  - Single $(\delta_{13}^d)_{LR}$ insertion

LL insertion - I





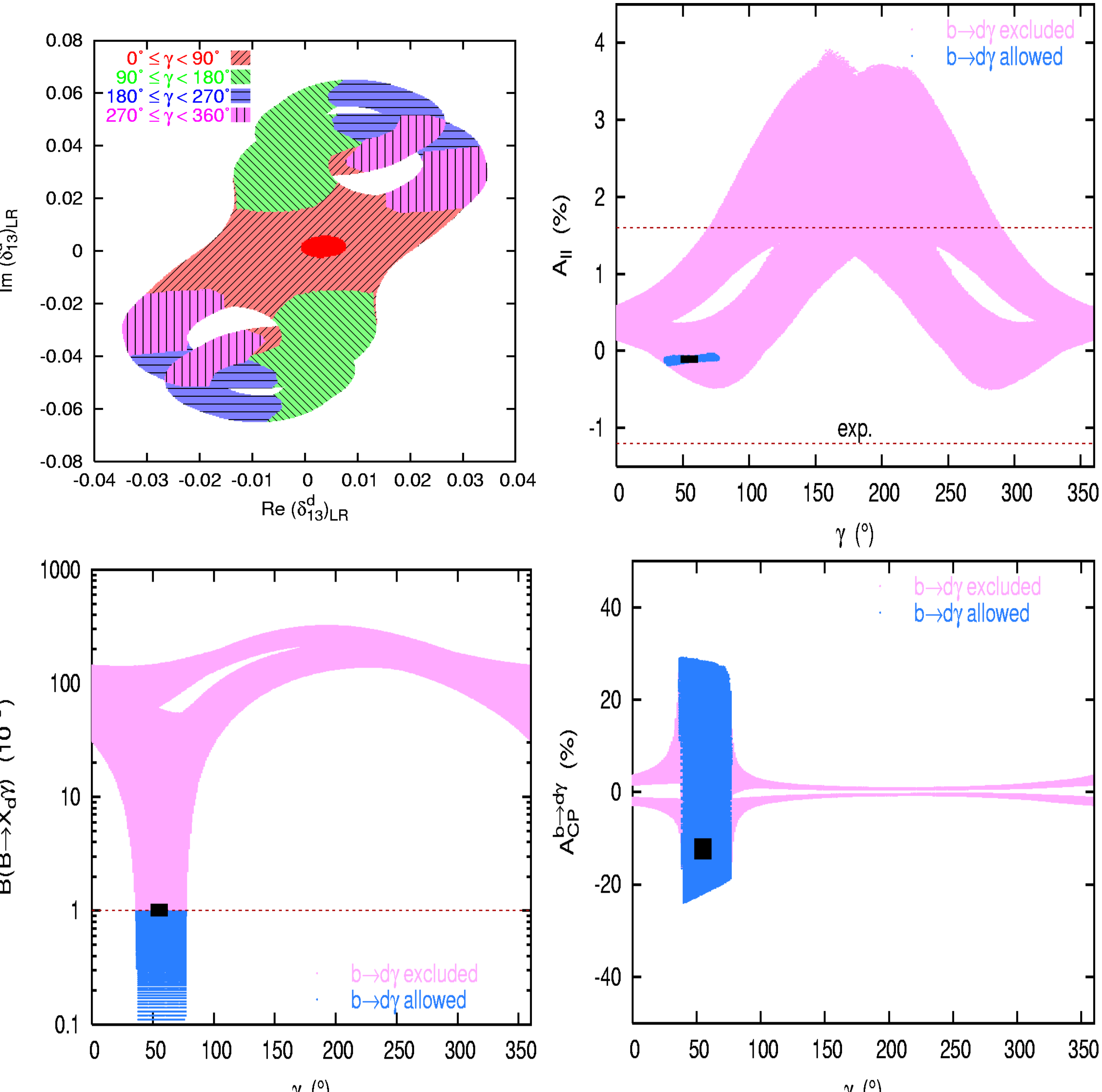




LL insertion - II

- Hatched region for $B(B \to X_d\,\gamma) > 1 \times 10^{-5}$
- A_{ll} can have sign opposite to that of SM value
- $B \to X_d\,\gamma$ strongly constrains $|(\delta^d_{13})_{LL}| \lesssim 0.2$
  $\rightsquigarrow\ -60^\circ \lesssim \gamma \lesssim 60^\circ$
- $-15\% \lesssim A_{\rm CP}^{b\to d\gamma} \lesssim +20\%$

LR insertion - I



LR insertion - II

- Hatched region for $B(B \to X_d\,\gamma) > 1 \times 10^{-5}$
- $B \to X_d\,\gamma$ even more strongly constrains $|(\delta^d_{13})_{LR}| \lesssim 10^{-2}$
  $\rightsquigarrow\ 30^\circ \lesssim \gamma \lesssim 80^\circ$
- Nevertheless, $-25\% \lesssim A_{\mathrm{CP}}^{b\to d\gamma} \lesssim +30\%$
- Not much effect on A_{ll}.
- Can expect large deviations in $B \to X_d\gamma$ even if $\gamma = \gamma_{\mathrm{SM}}$

Implications of the recent measurements of $B_s - \overline{B_s}$ mixing on SUSY models

$B_s - \overline{B_s}$ mixing in SM

- Dominated by the box diagram with $W - t$ in the loop
- The mixing is almost real within the SM , and depend on V_{ts}
- Any phase in the mixing is a clear signal of physics beyond the SM
- $\Delta M_d / \Delta M_s$ depends on $|V_{td}|^2 / |V_{ts}|^2$ with less hadronic uncertainties than individuals
  $\rightarrow$ Important for CKM Phenomenology

First observations of $B_s - \overline{B_s}$ mixing

- The WA before 2006 : $\Delta M_s > 14.4$ ps^{-1}
- D0 : 17 ps$^{-1} < \Delta M_s < 21\text{ps}^{-1}$
- CDF : $\Delta M_s = (17.33^{+0.42}_{-0.21}(\text{stat}) \pm 0.07(\text{sys}))$ ps^{-1}
- Constraint on V_{ts} from $\Delta M_d / \Delta M_s$
  $|V_{td}|/|V_{ts}| = 0.208^{+0.008}_{-0.007}(\text{stat} + \text{sys})$
- The Belle result from $b \to d\gamma$:
  $|V_{td}|/|V_{ts}| = 0.199^{+0.026}_{-0.025}(\text{exp})^{+0.018}_{-0.015}(\text{theor})$
- Excellent agreement of two measurements
  $\to$ Another test of the CKM paradigm and strong constraint on new physics scenarios

Model independent approach –I

$B_q^0 - \overline{B_q^0}$ Mixing ($q = d$ or s) and Observables

- $M_{12}^q = (1 + h_q e^{2i\sigma_q}) M_{12}^{q\mathrm{SM}}$
- $\Delta M_q = |1 + h_q e^{2i\sigma_q}| M_{12}^{q\mathrm{SM}}$
- $S_{\psi K} = \sin[2\beta + \arg(1 + h_d e^{2i\sigma_d})]$
- $S_{\psi\phi} = \sin[2\beta_s + \arg(1 - h_s e^{2i\sigma_s})]$
- $A_{\mathrm{SL}}^q = \mathrm{Im}\left[\frac{\Gamma_{12}^q}{M_{12}^q(1+h_q e^{2i\sigma_q})}\right]$
- $\beta_s = \arg\left[-(V_{ts}V_{tb}^*/(V_{cs}V_{cb}^*)\right] \approx 1^\circ$
- Γ_{12}^q : the absorptive part of the $B_q^0 - \overline{B_q^0}$ mixing

Model independent approach – II

- D0 result on semileptonic CP asymmetry :

$$
\begin{aligned}
A_{\mathrm{SL}} &\equiv \frac{\Gamma(b\bar{b} \to \mu^+\mu^+ X) - \Gamma(b\bar{b} \to \mu^-\mu^- X)}{\Gamma(b\bar{b} \to \mu^+\mu^+ X) + \Gamma(b\bar{b} \to \mu^-\mu^- X)} \\
&\simeq 0.506 A^d_{\mathrm{SL}} + 0.494 A^s_{\mathrm{SL}} \\
&= -0.957 \pm 0.251 \pm 0.146\%
\end{aligned}
$$

- BaBar, Belle and CLEO : $A^d_{\mathrm{SL}} = (-4.7 \pm 4.6) \times 10^{-4}$
- So one gets $A^s_{\mathrm{SL}} = -0.0146 \pm 0.0075$
  SM prediction: $\sim -2 \times 10^{-5}$

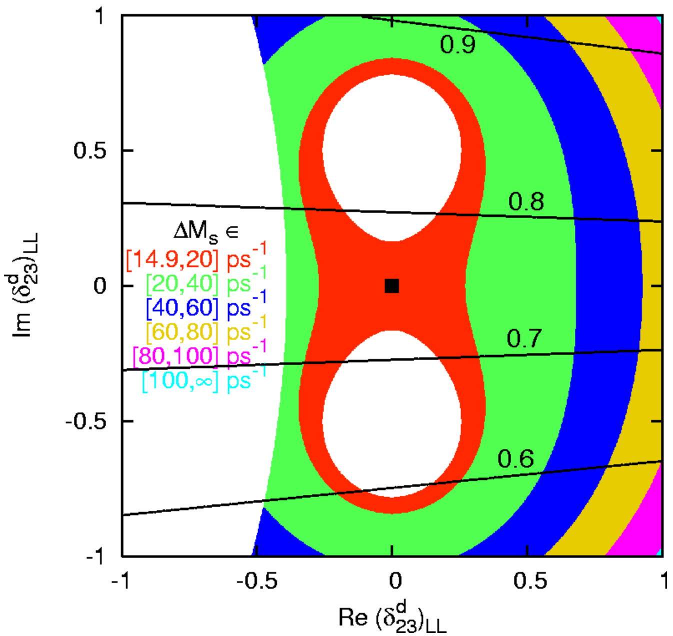
$B_s - \overline{B_s}$ mixing in SUSY models

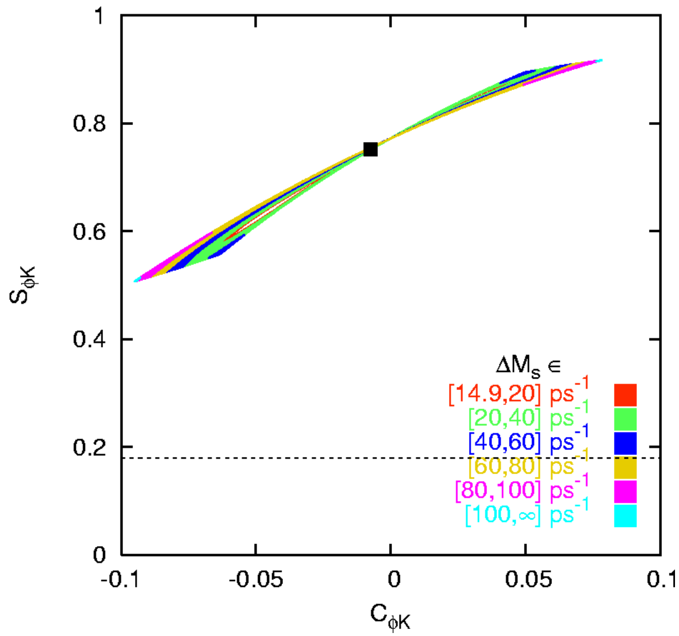
- Additional contributions from $H^- - t$, $\chi^- - \tilde{U}_i$ and $\tilde{D}_i - g(\tilde{\chi}^0)$
- In generic SUSY models, the squark-gluino loop is parametrically stronger, since it is strong interaction
- Assume that the dominant new physics contribution comes from down squark-gluino loop diagrams
- (see also Ciuchini and Silvestrini; Khalil, Endo and Mshima; Baek ...)
- See Ko, Kramer, Park, Eur.J.Phys. (2002) for $B_d - \overline{B_d}$ mixing, $A_{\rm SL}^d$ and CPV in $B \to X_d \gamma$
- See Kane, Ko, Kolda, Park, Wang^2, PRL (2003) and PRD (2004) for $B_d \to \phi K_s$ and $B_s - \overline{B_s}$ mixing and related issues

New Physics in $b \to s$ Before the CDF/D0 measurements

LL or RR-I (Kane,Ko,Kolda,Park,Wang[2])

- LL plots for $m_{\tilde{g}} = \tilde{m} = 400$ GeV





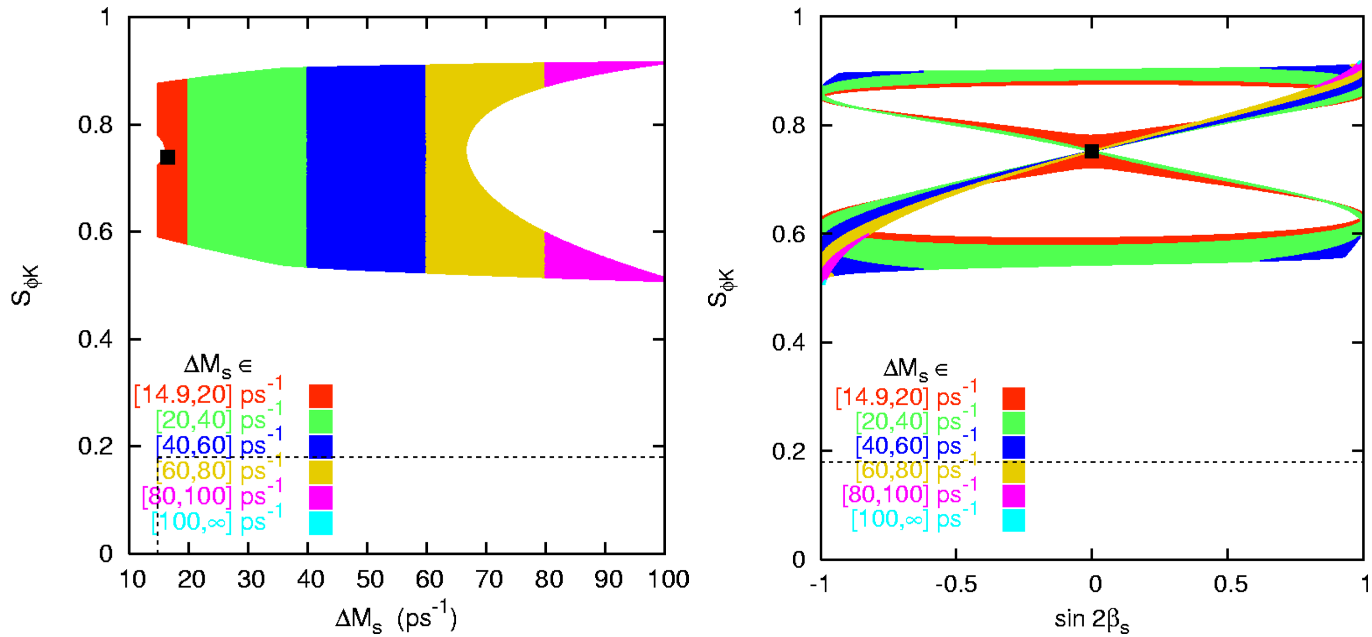
- $(\delta^d_{23})_{LL}$ can not significantly lower $S_{\phi K}$.

$$S_{\phi K} \gtrsim 0.05 \quad \text{for} \quad m_{\tilde{g}} = \tilde{m} = 250 \text{ GeV}$$

- Updated Value: $S_{\phi K} = 0.34 \pm 0.21$ (FPCP04)
- Now $S_{\phi K} = 0.47 \pm 0.19$ (Hazumi)

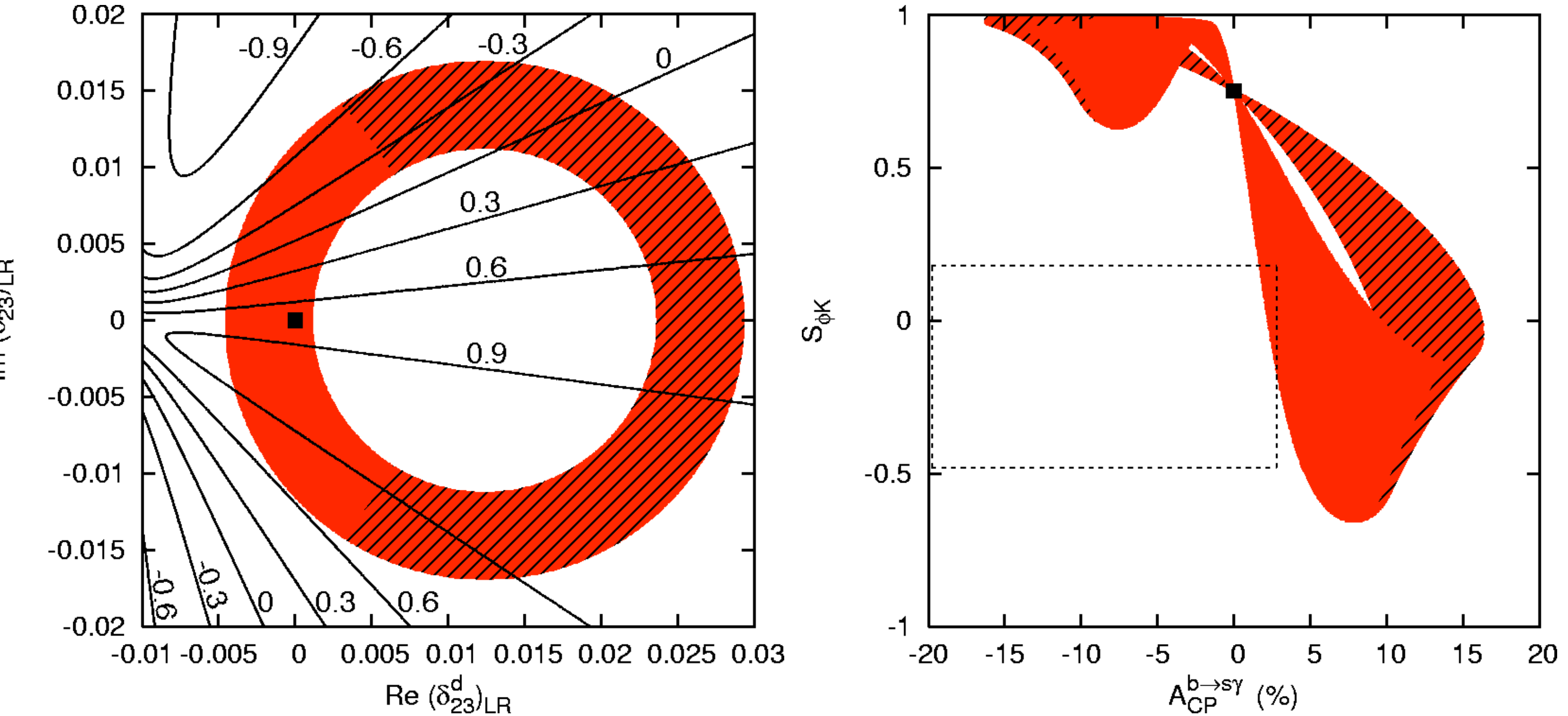
LL or RR-II

- But large effects possible in B_s–$\overline{B}_s$ mixing
  Both in the modulus and the phase



- Large ΔM_s & CP asymmetry in $B_s \to J/\psi\phi$
  $\to$ Nice subjects at hadron machines
- RR is similar to LL except for $B \to X_s\gamma$.

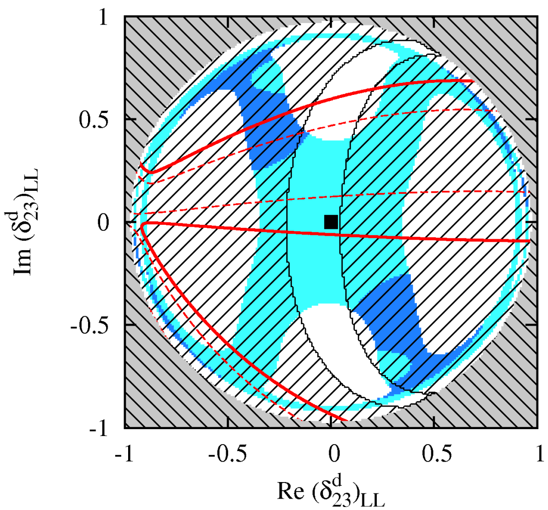
LR for $m_{\tilde{g}} = \tilde{m} = 400$ GeV



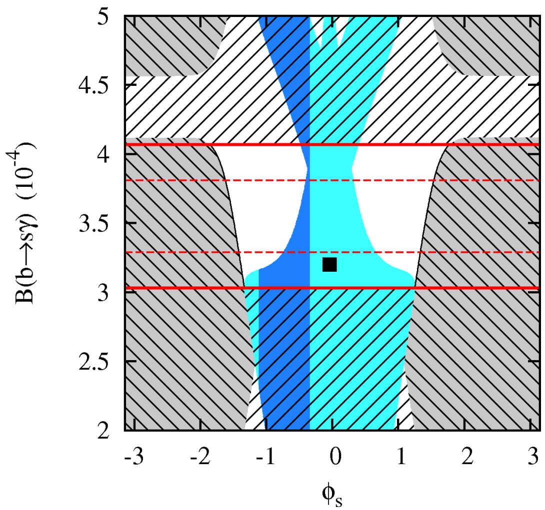
- $-0.6 < S_{\phi K} < 1$ for $|(\delta^d_{23})_{LR(RL)}| \sim 10^{-2}$
- $A_{\rm CP}^{b\to s\gamma}$ can be large compared w/ SM prediction
- Not much effect on B_s–$\overline{B}_s$ mixing

After the CDF/D0 measurements

LL insertion ($\tan\beta = 3$)



(a)



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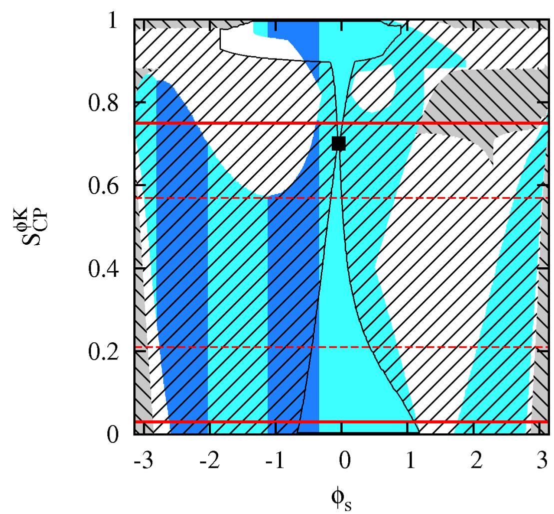
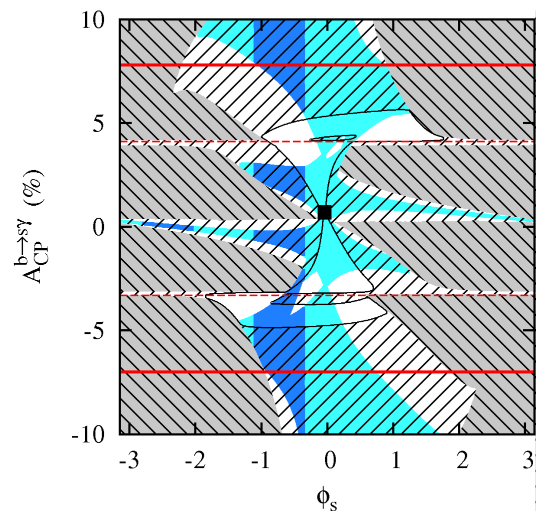


(c)

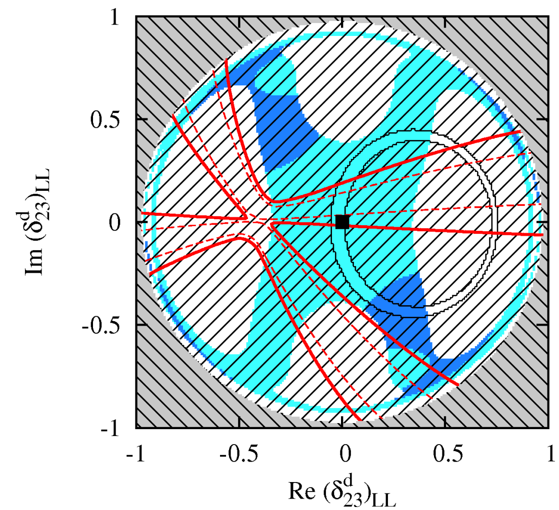


(d)

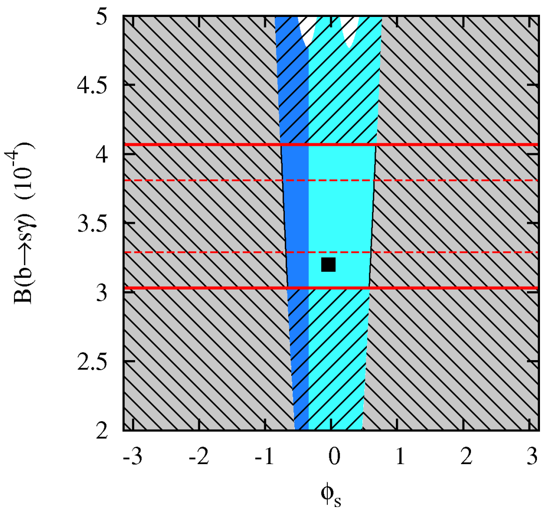
Captions

- Allowed regions on (a) $(\mathrm{Re}(\delta^d_{23})_{LL}, \mathrm{Im}(\delta^d_{23})_{LL}))$, and correlation between ϕ_s and each of (b) $B(B \to X_s\gamma)$, (c) $S_{\phi K}$, and (d) $A^{b\to s\gamma}_{\mathrm{CP}}$.
- The hatched gray region leads to the lightest squark mass < 100 GeV.
- The hatched region is excluded by the $B \to X_s\gamma$ constraint.
- The cyan region is allowed by ΔM_s.
- The blue region is allowed by the ΔM_s and ϕ_s.
- The black square is the SM point.
- In Fig. (a), bands bounded by red dashed and solid curves correspond to 1σ and 2σ ranges of $S_{\phi K}$, respectively.

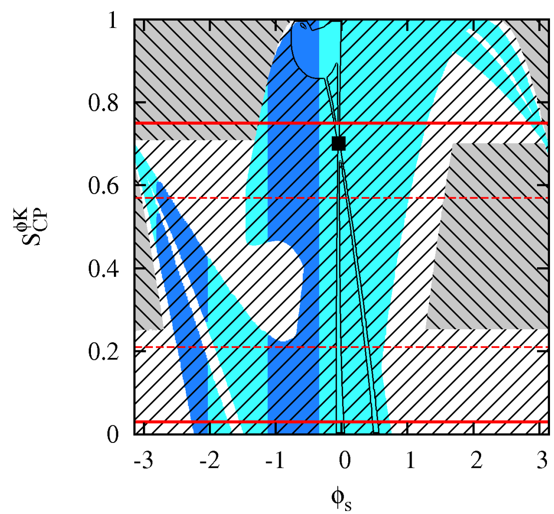
LL insertion ($\tan\beta = 10$)



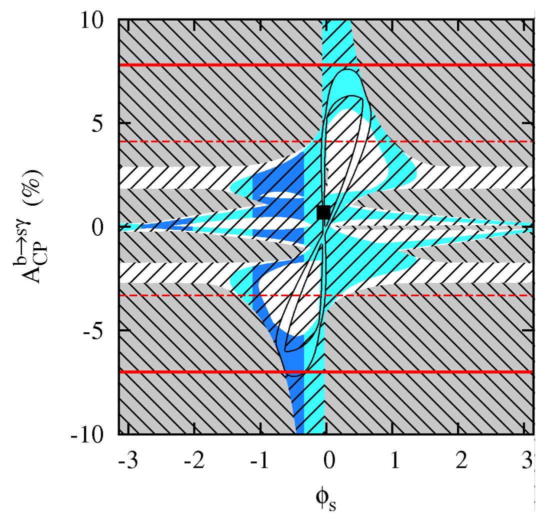
(a)



(b)

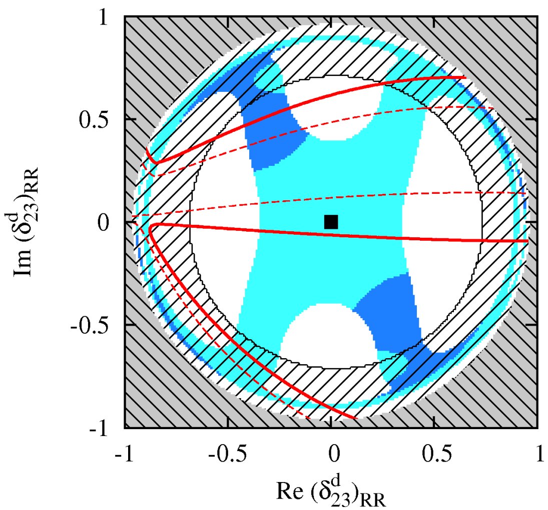


(c)

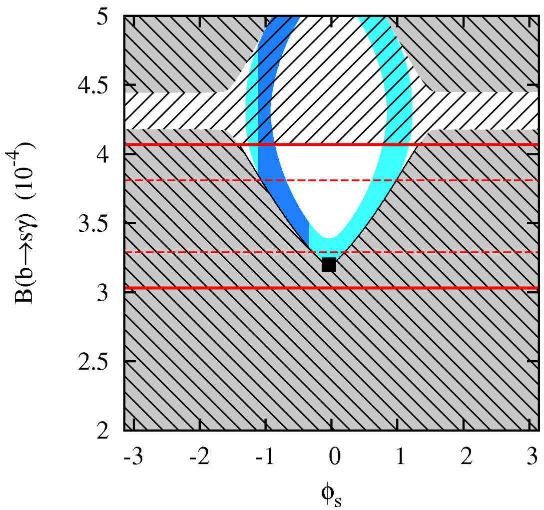


(d)

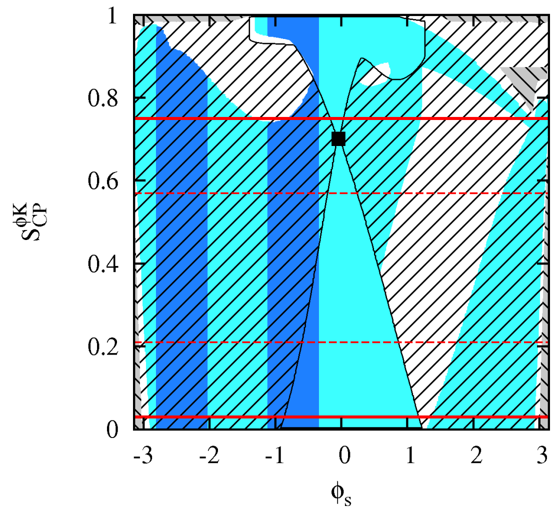
RR insertion ($\tan\beta = 3$)



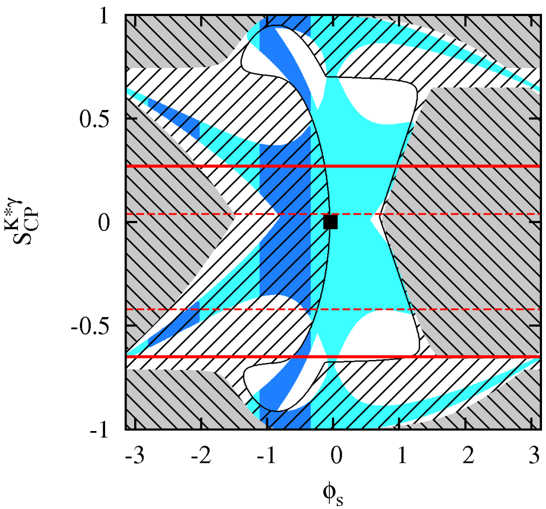
(e)



(f)

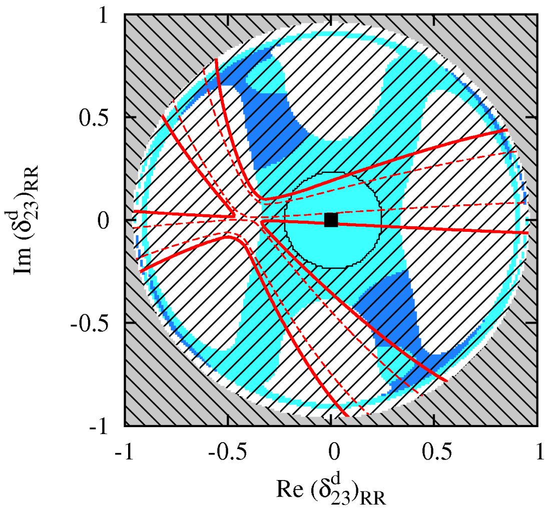


(g)

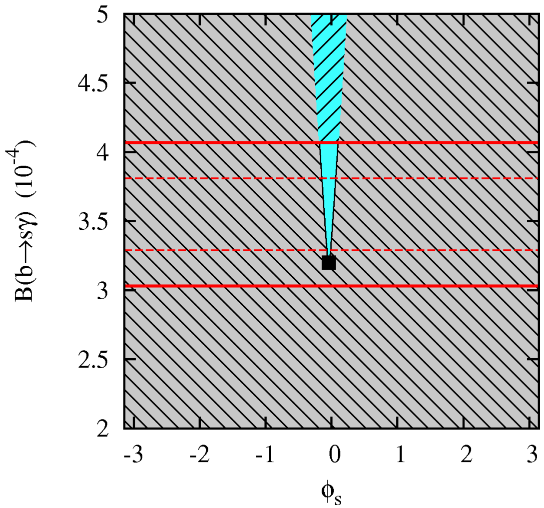


(h)

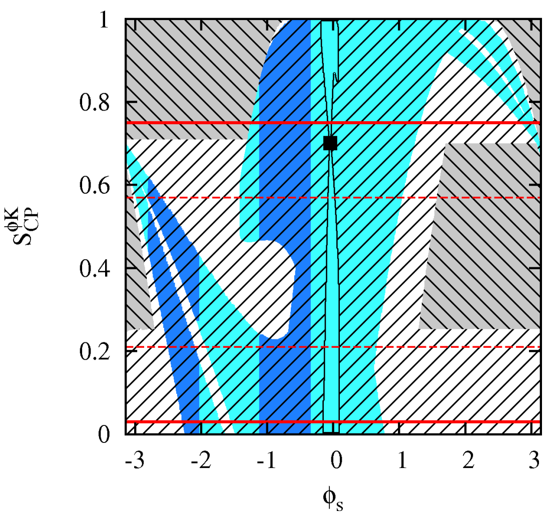
RR insertion ($\tan\beta = 10$)



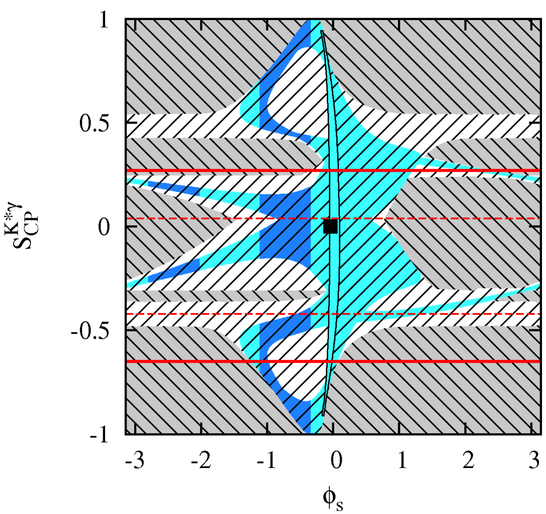
(i)



(j)

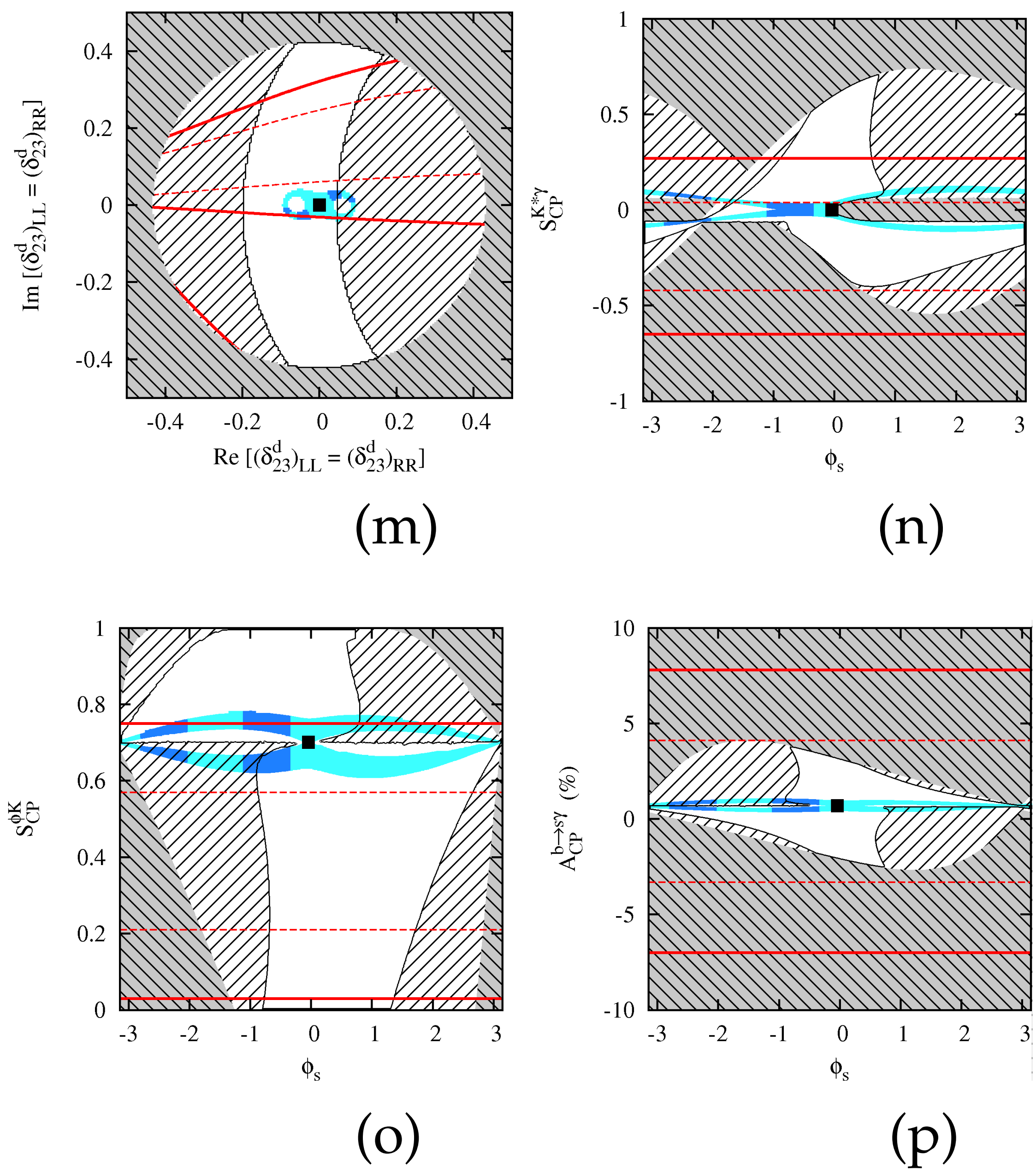


(k)

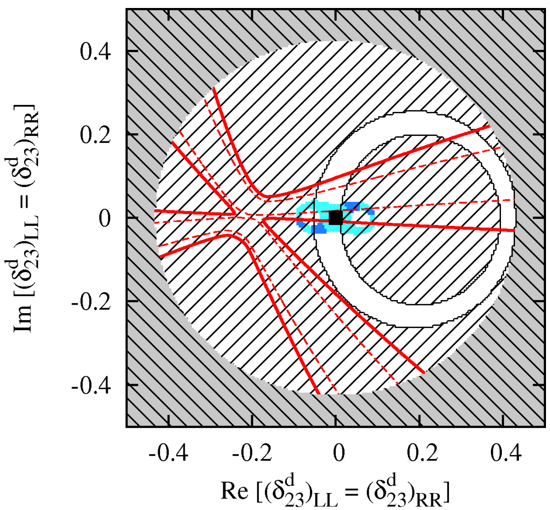


(l)

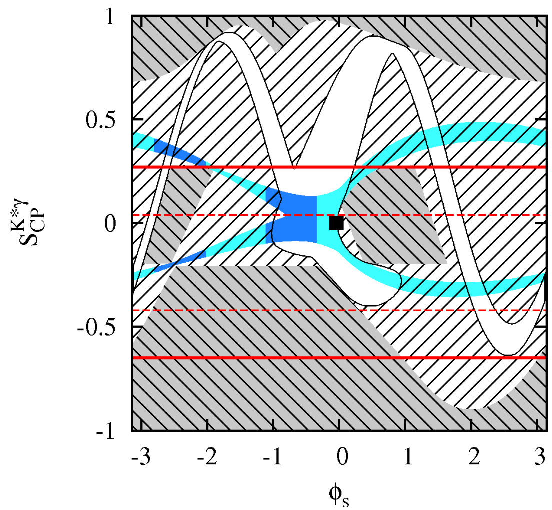
$LL = RR$ case ($\tan\beta = 3$)



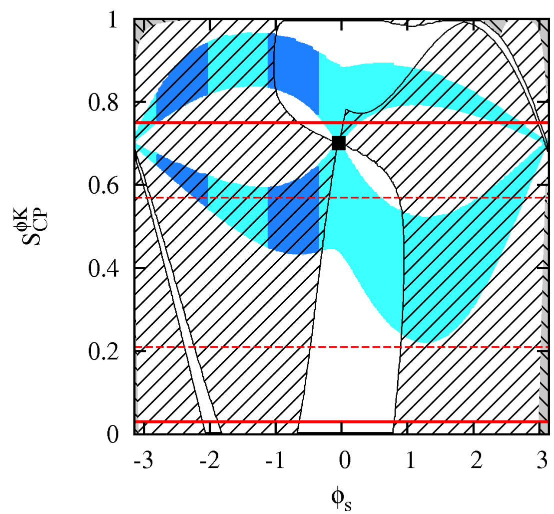
$LL = RR$ **case** ($\tan\beta = 10$)



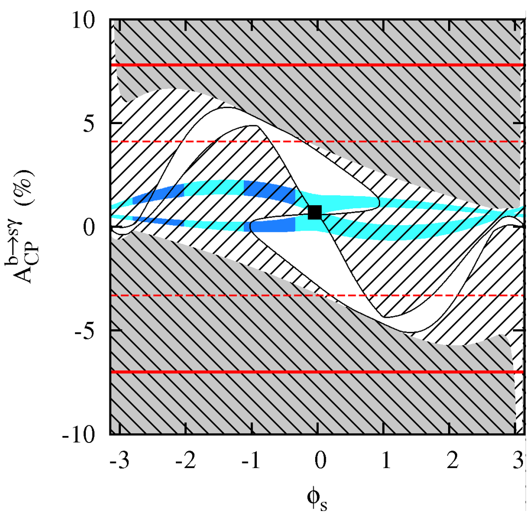
(q)



(r)

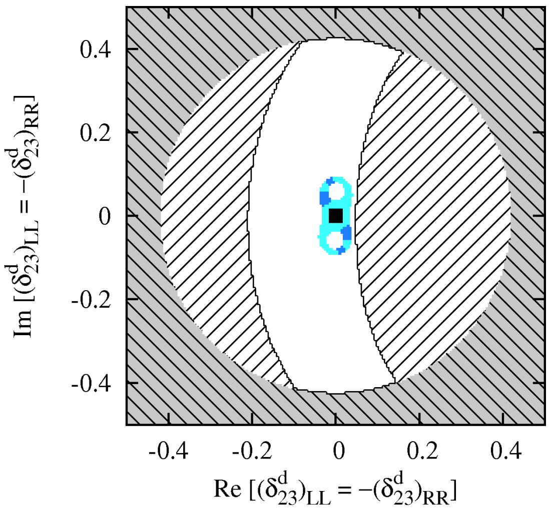


(s)

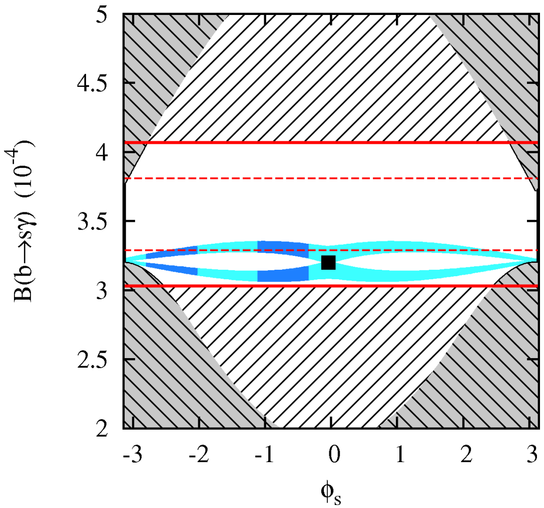


(t)

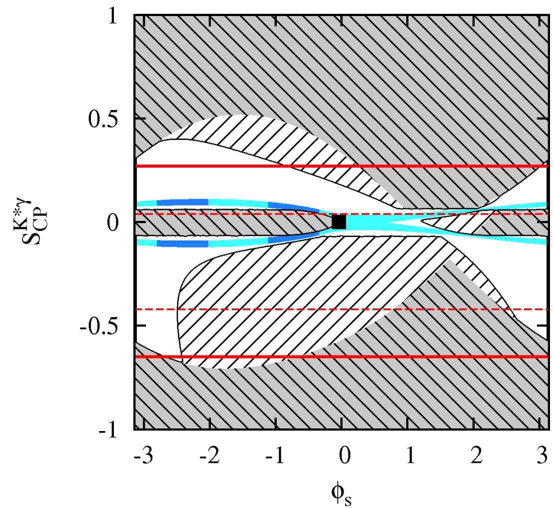
$LL = -RR$ case ($\tan\beta = 3$)



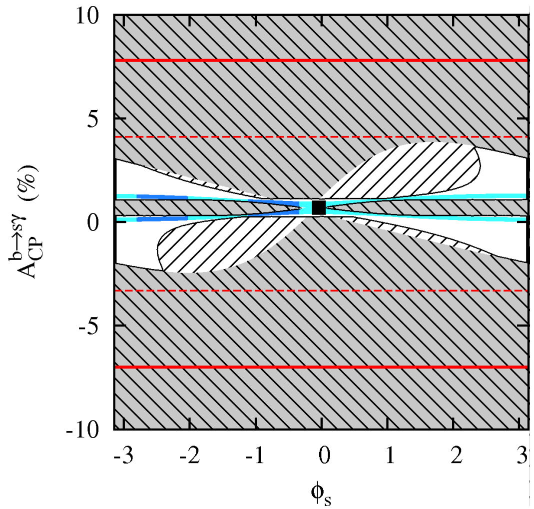
(u)



(v)

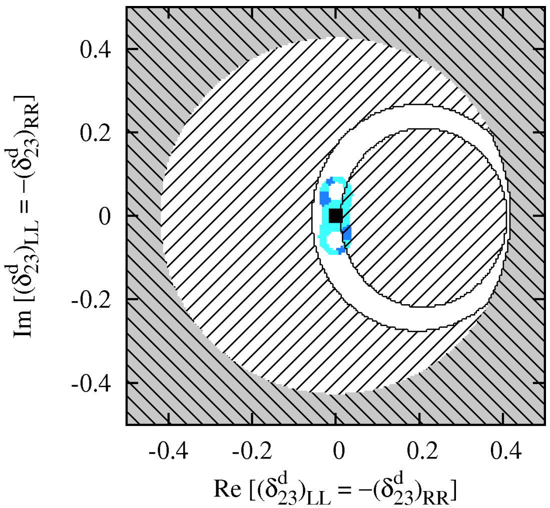


(w)

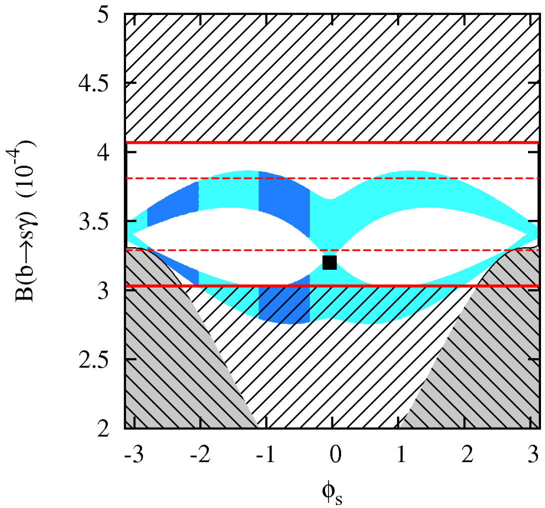


(x)

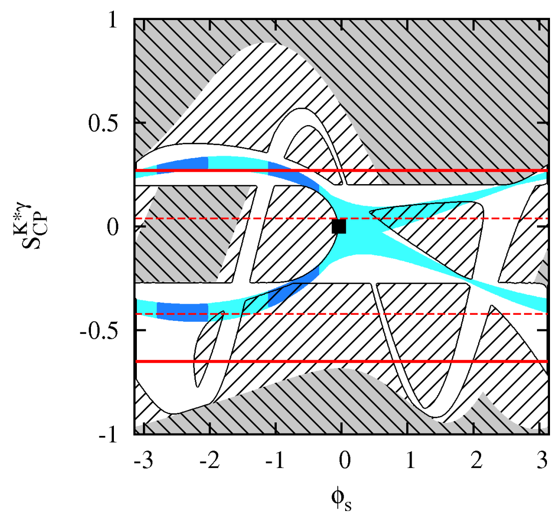
$LL = -RR$ case ($\tan\beta = 10$)



(y)



(z)



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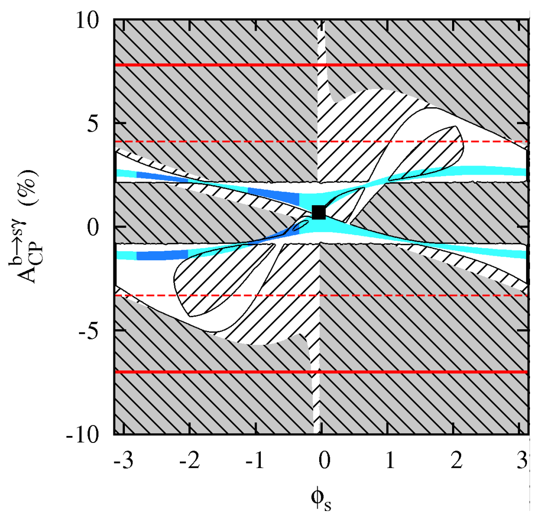
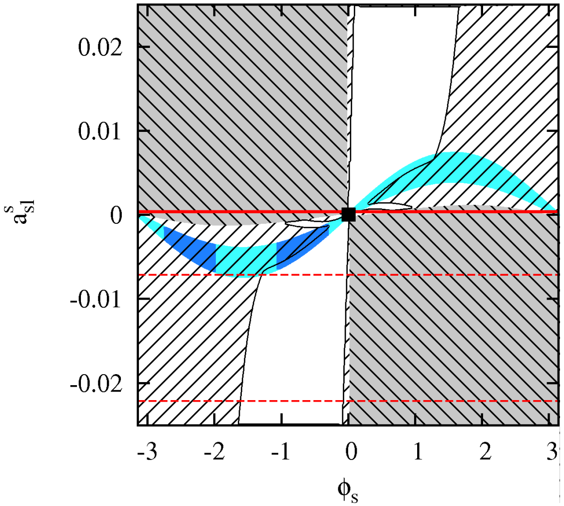
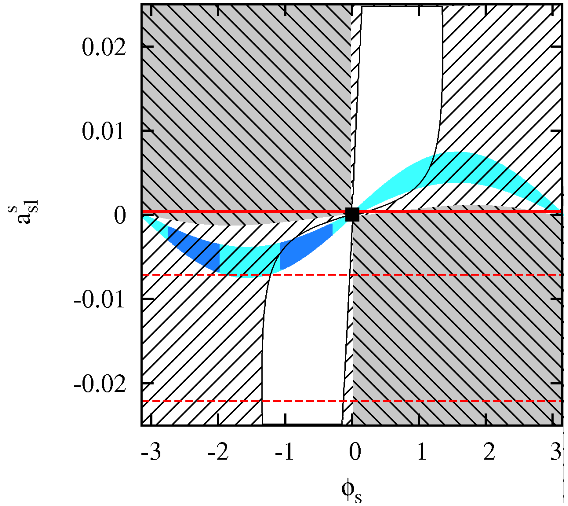


()

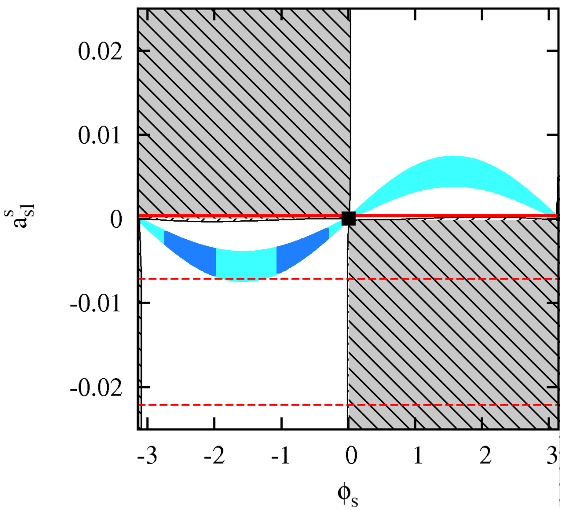
a_{SL} for $\tan\beta = 3$



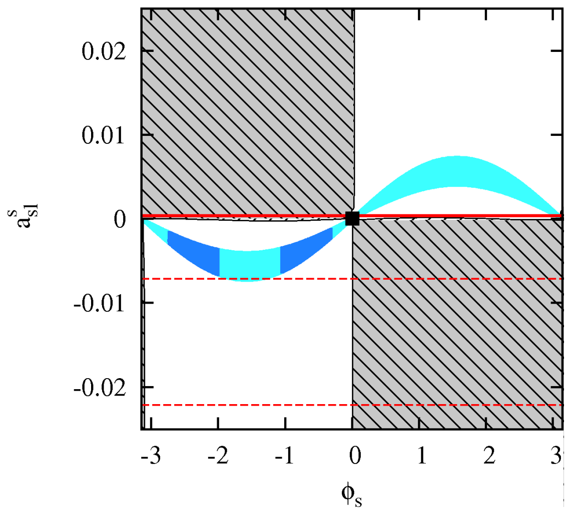
() LL



() RR



() $LL = RR$

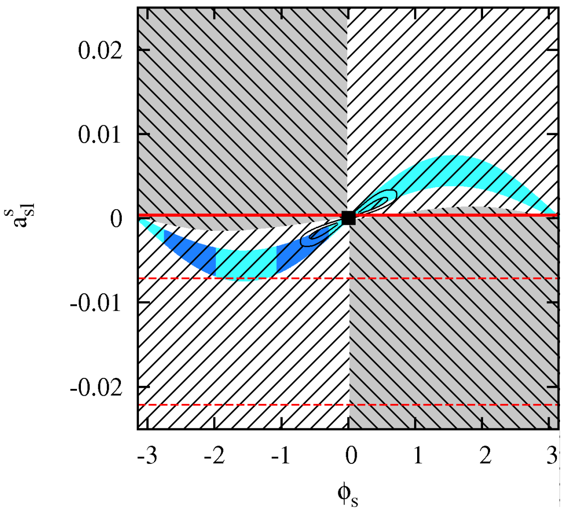


() $LL = -RR$

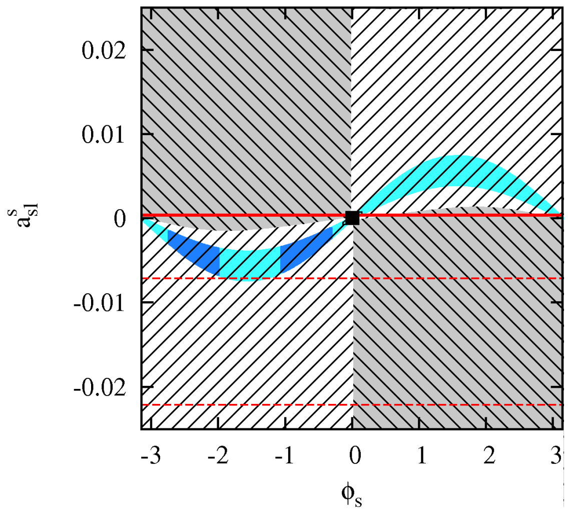
Captions

- The hatched gray region leads to the lightest squark mass < 100 GeV.
- The hatched region is excluded by the $B \to X_s\gamma$ constraint.
- The cyan region is allowed by ΔM_a.
- The blue region allowed both by ΔM_s and ϕ_s.
- The black square is the SM point.
- The red dashed and solid lines mark the 1σ and 2σ ranges of a_{SL}, respectively.

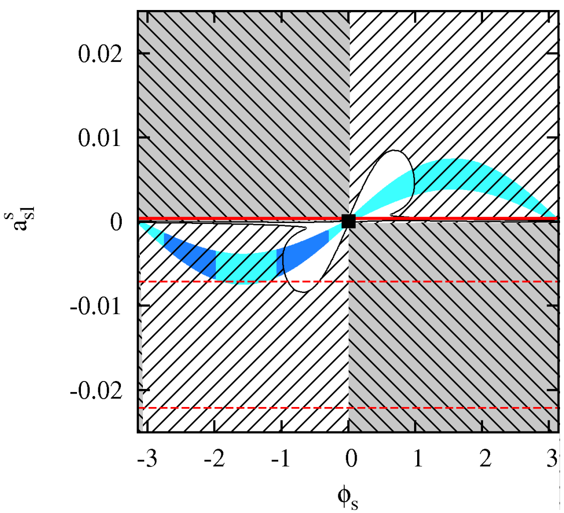
$a_{\rm SL}$ **for** $\tan\beta = 10$



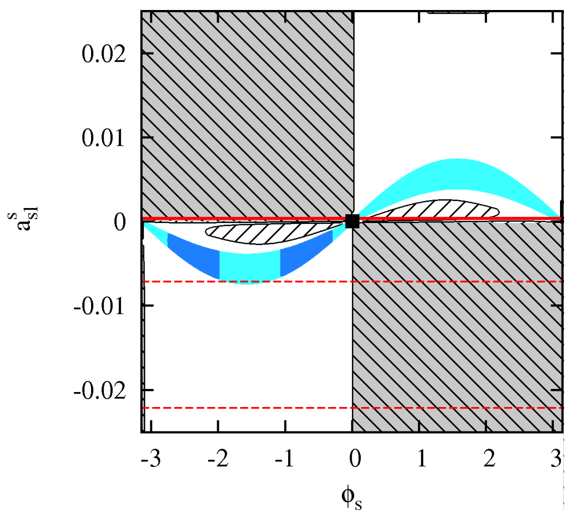
() LL



() RR



() $LL = RR$



() $LL = -RR$

Implications for SUSY models

- mSUGRA (?) or GMSB : Universal soft masses at some scale M_X,.....
  $\rightarrow \delta(M_X) = 0$
- δ's are generated by RG evolutions
- For example, in mSUGRA,

$$
\begin{aligned}
(m^2_{LL})_{ij}(\mu = M_{weak}) \;\; \simeq \;\; & -\frac{1}{8\pi^2} Y_t^2 \, (V_{\mathrm{CKM}})_{3i} \, (V^*_{\mathrm{CKM}})_{3j} \\
& \left(3m_0^2 + a_0^2\right) \, \log\left(\frac{M_*}{M_{\mathrm{weak}}}\right)
\end{aligned}
$$

- $(\delta^d_{LL})_{23} \simeq 9 \times 10^{-3}$ and $(\delta_{LL})_{13} \simeq 8 \times 10^{-3} \times e^{-i2.7}$
- $(\delta^d_{LL})_{23}$ is real , no CPV phase $\rightarrow$ No effect on $S_{\phi K}$

δ_{RR} from SUSY GUT with Seesaw

- For example, in SU(5)+RHN's, Moroi argues

$$(m^2_{\tilde{d}})_{ij} \simeq -\frac{1}{8\pi^2}[Y_N^\dagger Y_N]_{ij}(3m_0^2 + A^2)\log\frac{M_*}{M_{\rm GUT}}$$

$$\simeq -e^{-i(\phi_i^{(L)}-\phi_j^{(L)})}\frac{y^2_{\nu_k}}{8\pi^2}[V_L^*]_{ki}[V_L]_{kj}(3m_0^2 + A^2)\log\frac{M_*}{M_{\rm GUT}}.$$

- $|(\delta^d_{RR})_{23}| \simeq 2 \times 10^{-2}\left(\frac{M_{N_3}}{10^{14}\ \rm GeV}\right)$ with $O(1)$ phase
- And RG induced δ's can be small enough to evade the constraint from $B_s - \overline{B_s}$ mixing, and the double mass insertion can induce effective RL insertion
  $\rightarrow$ Can affect $S_{\phi K}$

Induced LR or RL from Double Mass Insertion

$$(\delta^d_{LR})^{\text{ind}}_{23} = (\delta^d_{LL})_{23} \times \frac{m_b(A_b - \mu \tan\beta)}{\tilde{m}^2}.$$

- $(\delta^d_{LL,RR})_{23} \sim 10^{-2} \to (\delta^d_{LR,RL})^{\text{ind}}_{23} \sim 10^{-2}$, if $\mu \tan\beta \sim 30$ TeV.
- Natural if $\tan\beta$ is large ~ 40
- For larger LL, RR mixing, even smaller $\mu \tan\beta$ would suffice to induce the needed LR, RL mass insertions of a size $10^{-2} - 10^{-3}$.
- $\delta_{LL,RR}$'s in SUSY flavor models are generically complex, the induced $(\delta^d_{LR})^{\text{ind}}_{23}$ could carry a new CP violating phase leading to deviation in $S_{\phi K}$

Implications for SUSY flavor models

Model	$\lvert\delta^{23}_{d,LL}\rvert$	$\lvert\delta^{23}_{d,RR}\rvert$	$\tan\beta = 3$	$\tan\beta = 10$
LNS (A)	λ^2	λ^4	$\cdot$	$\surd$
NS ; CHM (A)	λ^2	1	$\times$	$\times$
NR (A)	λ^2	λ^8	$\cdot$	$\surd$
CHM (NA)	λ^2	$\lambda^{1/2}$	$\times$	$\times$
BHRR, PT (NA)	λ^2	λ^2	ϕ_s	$\surd$
HM (NA)	λ^3	λ^5	$\cdot$	$\cdot$
PS (NA)	λ^2	λ^4	$\cdot$	$\surd$
CKN (D)	λ^2	$LL \gg RR$	$\cdot$	$\surd$

Status of some models analyzed Randall and Su, for the two different values of $\tan\beta$. (A=Abelian, NA=Nonabelian, D=Decoupling) ($\cdot$) incompatible with ϕ_s but safe otherwise; (ϕ_s) compatible with ϕ_s and safe; ($\surd$) currently okay but dangerous; ($\times$) disfavored.

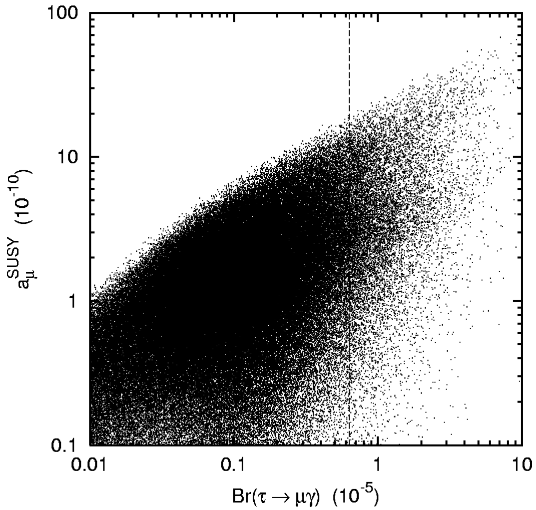
Digression on $(g-2)_\mu$ in effective SUSY

- Hagiwara, Liao, Martin, Nomura, Teubner [arXiv:1001.5401]:

$$\Delta a_\mu = (31.6 \pm 7.9) \times 10^{-10}$$

- Baek, Ko, Park: EPJC 24, 613 (2002)
  - Strong correlation between $B(\tau \to \mu\gamma)$ and $(g-2)_\mu$ in effective SUSY model
  - $B(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$
  - $a_\mu^{\rm SUYS} \lesssim 2(0.6) \times 10^{-10}$ for $\tan\beta = 3(30)$
- See plots

Plots for $(g-2)_\mu$ in effective SUSY



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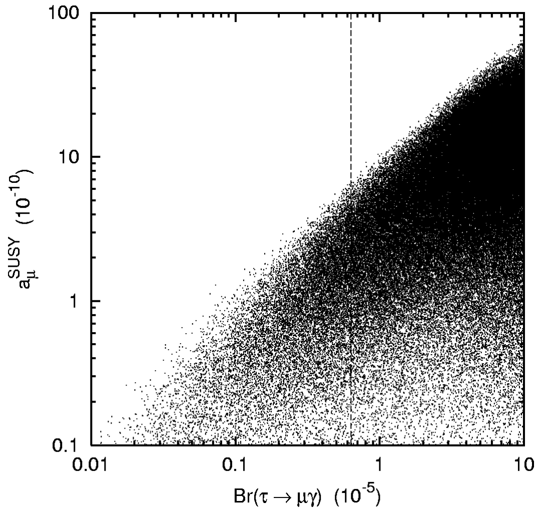

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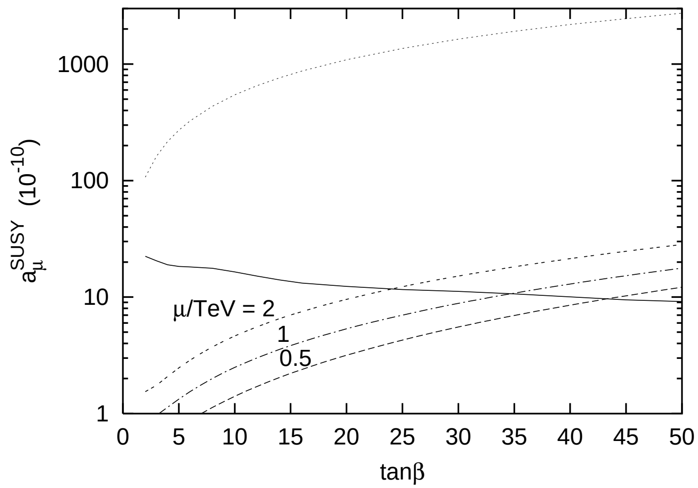

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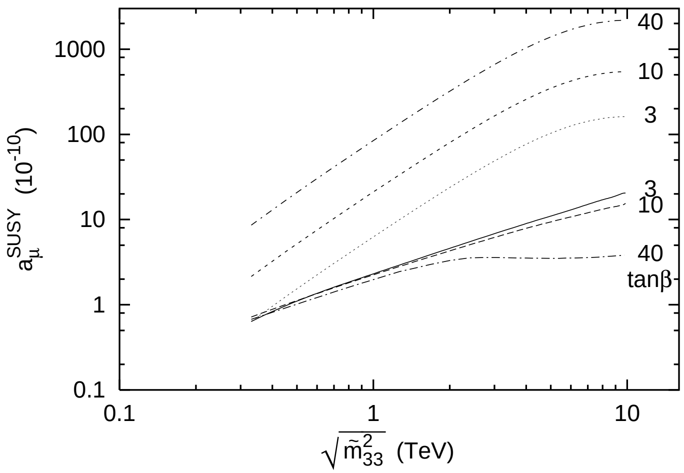

()

Conclusion

- $B_s - \overline{B_s}$ mixing excludes some SUSY flavor models based on (non)abelian flavor symmetries
- The LL or RR insertions for small $\tan\beta$ case cannot be large as in the past ($\lesssim 0.5$)
- Large $\tan\beta$ case is strongly contrained by $b \to s\gamma$ (independent of m_A) and by $B_s \to \mu^+\mu^-$ for light m_A; For moderately high $\tan\beta$, $O(1)$ value of ϕ_s tends to conflict with $B \to X_s\gamma$ in the four cases considered here
- The $LL = \pm RR$ case is even more strongly contrained by ΔM_s measurement
- The LR or RL insertions consistent with $b \to s\gamma$ is still OK with ΔM_s, since it does not affect the $B_s - \overline{B_s}$ mixing; however for the same reason, it cannot make

Most important is to reach the experimental sensitivity to confirm/falsify the SM predictions for A_{SL}