Issues in B physics at the Tevatron

Invited talk at Tevatron B workshop, KISTI, Aug.24 (2009))

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Based on works in collaborations with

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- B physics within EWBGEN MSSM
- (SUSY GUT : LFV vs. B physics, 4th generation)
- Charmonium Spectroscopy
- Concluding Remarks

Current status of CKM paradigm

CKM matrix

- Weak interaction eigenstates $\leftrightarrow$ mass eigenstates

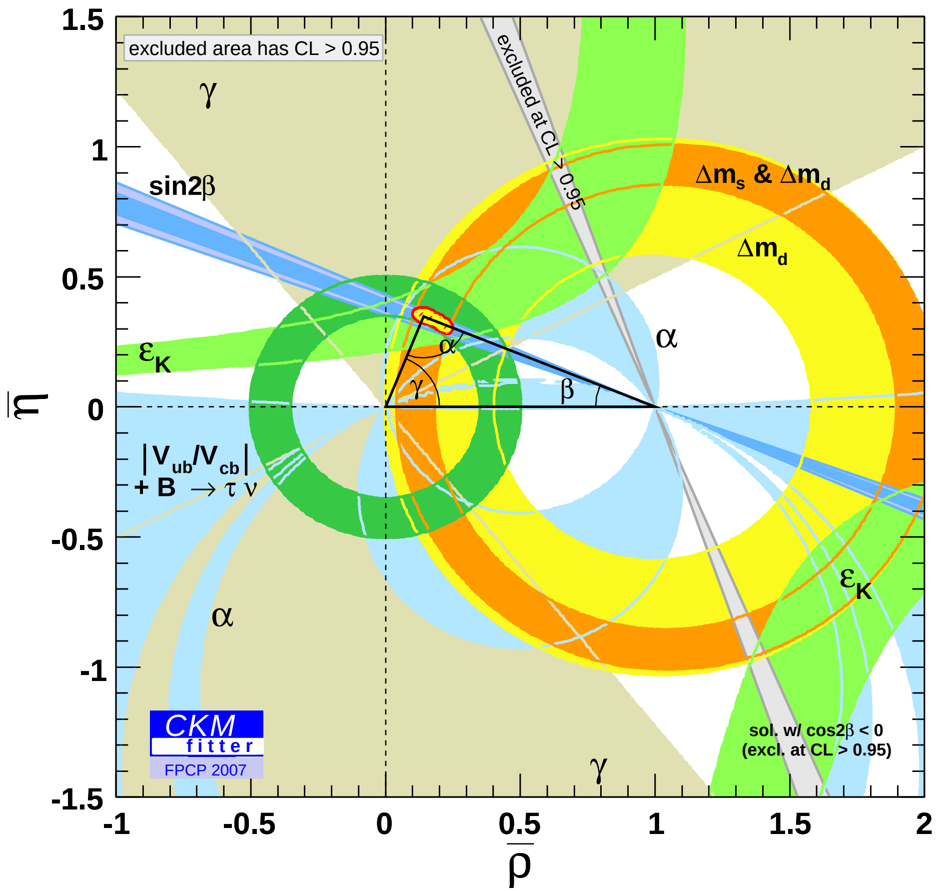
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}_L = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_L$$

- CKM matrix is hierarchical and has one CP phase.

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

- $V^\dagger V = VV^\dagger = \mathbf{1} \rightarrow$ unitarity triangles (UT).
- If UT doesn't close, a signature of new physics

UT on the (ρ, η) plane



- Consistent with the CKM paradigm
- Highly nontrivial

Current status of CKM paradigm

- So far, so good !
- Additional flavor/CP violations in any new physics around TeV scale should be small ($\longrightarrow$ MFV ?)
- Why new physics is flavor blind is another fine tuning problem in any new physics beyond the SM, including SUSY models
- Despite of the nice results on CKM fit, this is not the end. Even if the shape of the UT is the same as this SM fit, there are processes with large deviations (within SUSY models) $\longrightarrow$ See next slide

What's next in the LHC era ?

- Precision tests of the CKM paradigm ($\lesssim$ 5% level ?)
  $\longrightarrow$ Need improvement in QCD parts
- Where can we see large deviations from the SM predictions ?
  CP asymmetries in $B \to X_{s(d)}\gamma$, $B \to \phi K_S$, and
  $B_s \to J/\psi\phi$ (the phase of $B_s - \overline{B_s}$ mixing)
  $B_s \to \mu^+\mu^-$
  These should be measured accurately for the complete test of the CKM paradigm
- SUSY GUT $\longrightarrow$ Connections between quark and lepton sectors
  $\mu \to e\gamma$, $\tau \to \mu\gamma$, etc. could be related with $B \to \phi K_s$, $B \to X_s\gamma$, etc.

Big Question: Anything new at TeV scale ?

Answer I: Just a SM(like) Higgs and nothing else

- Only SM + DM + Neutrino masses and mixings
- Not many things to do in quark flavor physics, just precision measurements of the known CKM elements (Need lattice QCD)
- More to do in neutrino sector, measuring θ_{13} and $\delta_{\rm CP}$ in PMNS matrix
- DM physics : no generic direct relation with flavor physics
  Exception: $B_s \to \mu^+\mu^-$ and direct detection rate (spin-independent scattering cross section) in MSSM
- LHC would become a QCD laboratory
- Not an encouraing answer, although could be the case

Big Question: Anything new at TeV scale ?

Answer II: YES, THERE IS SOMETHING NEW

- Fine tuning Δm_H^2 calls for something new at TeV scale
- However, flavor physics constrains the new physics scale should be ~ 100 TeV or higher
  $\longrightarrow$ Some tension between two
- Gauge coupling unification, DM, etc., calls for something new

THEN, WHAT IS IT ?

SUSY? Technicolor ? Randall-Sundrum ?

Little Higgs ? Extra dim ??? Completely NEW ?

EW scale SUSY: MSSM

- Assume MSSM is the new physics around TeV scale (fine tuning, gauge coupling unification, CDM)

$$\mathcal{L} = \mathcal{L}_{\text{SUSY}} + \mathcal{L}_{\text{Soft SUSY Breaking}}$$

- Masses and trilinear couplings in soft SUSY breaking terms are flavor and CP violating in general $\rightarrow$ Can affect flavor physics (K, B, μ, τ...)
- LHC can discover new particles and measure their masses, couplings, etc. to some extent.
- Not easy to determine flavor and CP violating couplings at LHC
- K, B physics results can give some informations on these couplings, being complementary to the LHC experiments

Complementarity between LHC and Super B

- Still possible to have large deviations in some channels, a number of them can be studied only at Super B, and not at LHC
- Squarks/gluios heavier than ~ 2 TeV can leave a footprint in $B \to \phi K_S$ or CP asymmetry in $B \to X_s \gamma$ through a small amount of LR mixing $\tilde{b}_{L(R)} - \tilde{s}_{R(L)}$
- $B \to X_s \nu \bar{\nu}$ can be studied at Super B
(Could be sensitive to light dark matter)
- Super B could be much more powerful than LHC, when we seek for new physics effects with flavor/CP violation

Basic Strategies

- “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

Possible large deviations from SM predictions

- $b \longrightarrow d$ transition
- $b \longrightarrow s$ transition
- $B_s \longrightarrow \mu^+\mu^-$

$b \to d$ Transition

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^d_{13}'s as well as $\gamma(\phi_3)$ (KM angle)
- Constraints

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

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

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

(Not updated)

1-3 Mixing : Cont'd

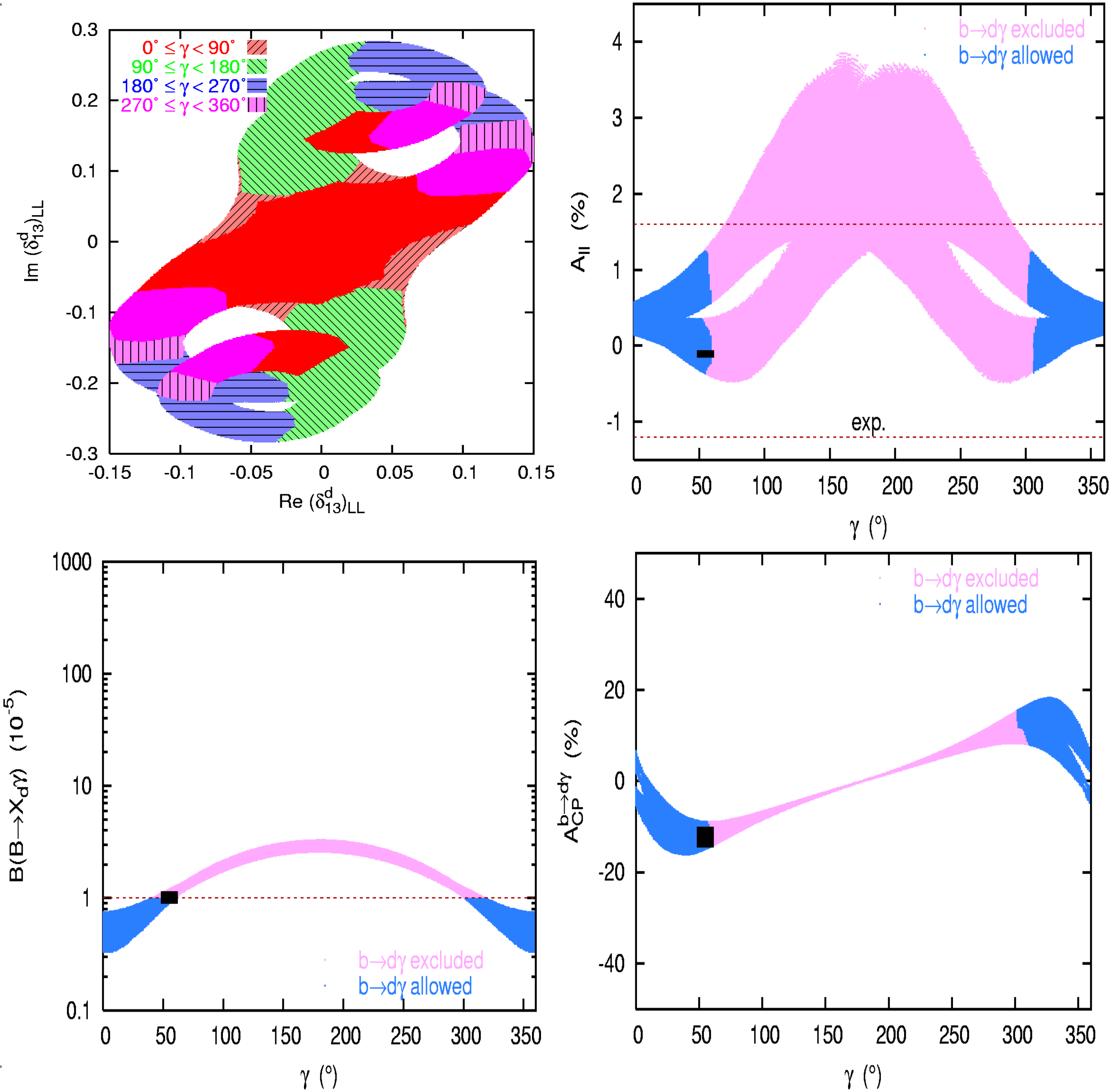
- Predictions

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

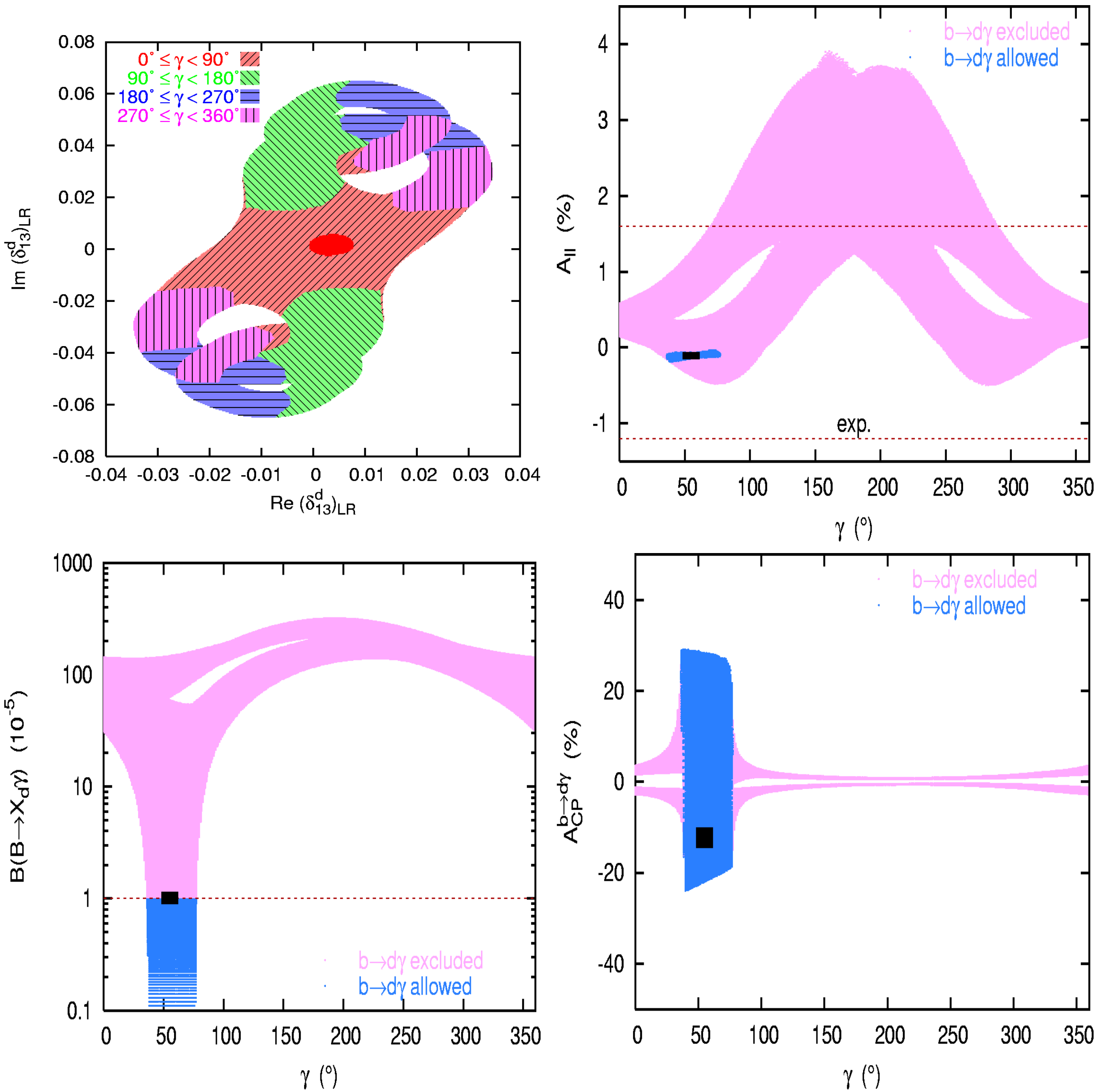
$$A_{\mathrm{CP}}^{b\to d\gamma} \equiv \frac{\Gamma(B \to X_d\,\gamma) - \Gamma(\overline{B} \to \overline{X_d}\,\gamma)}{\Gamma(B \to X_d\,\gamma) + \Gamma(\overline{B} \to \overline{X_d}\,\gamma)}$$

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

LL insertion



LR insertion



$b \to s$ **transition**

$B_s - \overline{B_s}$ 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 until March 2006 : $\Delta M_s > 14.4$ ps^{-1}
- D0 : 17 ps$^{-1} < \Delta M_s < 21 \mathrm{ps}^{-1}$
- CDF : $\Delta M_s = (17.33^{+0.42}_{-0.21}(\mathrm{stat}) \pm 0.07(\mathrm{sys}))$ ps^{-1}
- Constraint on V_{ts} from $\Delta M_d / \Delta M_s$
  $|V_{td}|/|V_{ts}| = 0.208^{+0.008}_{-0.007}(\mathrm{stat}+\mathrm{sys})$
- The Belle result from $b \to d\gamma$:
  $|V_{td}|/|V_{ts}| = 0.199^{+0.026}_{-0.025}(\mathrm{exp})^{+0.018}_{-0.015}(\mathrm{theor})$
- 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

(Ligeti, Papucci, Perez, hep-ph/0604112)

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

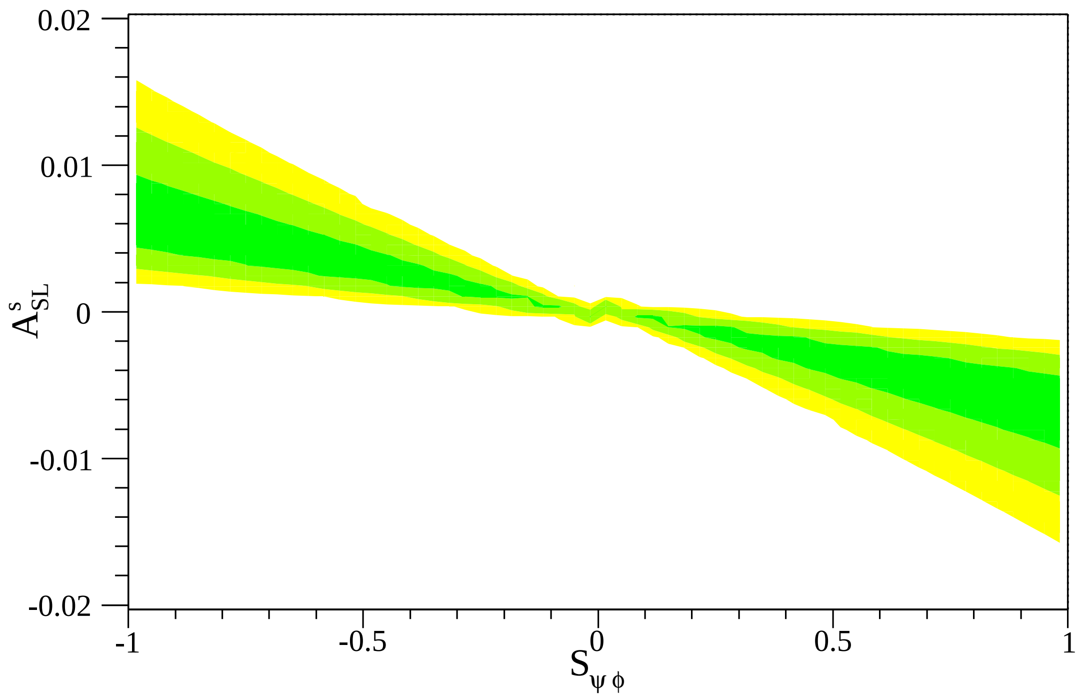
Model independent approach – II

- D0 result on semileptonic CP asymmetry (this March) :

$$
\begin{aligned}
A_{\mathrm{SL}} &\equiv \frac{\Gamma(b\bar{b} \to \mu^+\mu^+ X) - \Gamma(b\bar{b} \to \mu^-\mu^- X)}{\Gamma(b\bar{b} \to \mu^+\mu^+ X) + \Gamma(b\bar{b} \to \mu^-\mu^- X)} \\
&\simeq 0.6 A_{\mathrm{SL}}^d + 0.4 A_{\mathrm{SL}}^s \\
&= -0.0044 \pm 0.0040 \pm 0.0028
\end{aligned}
$$

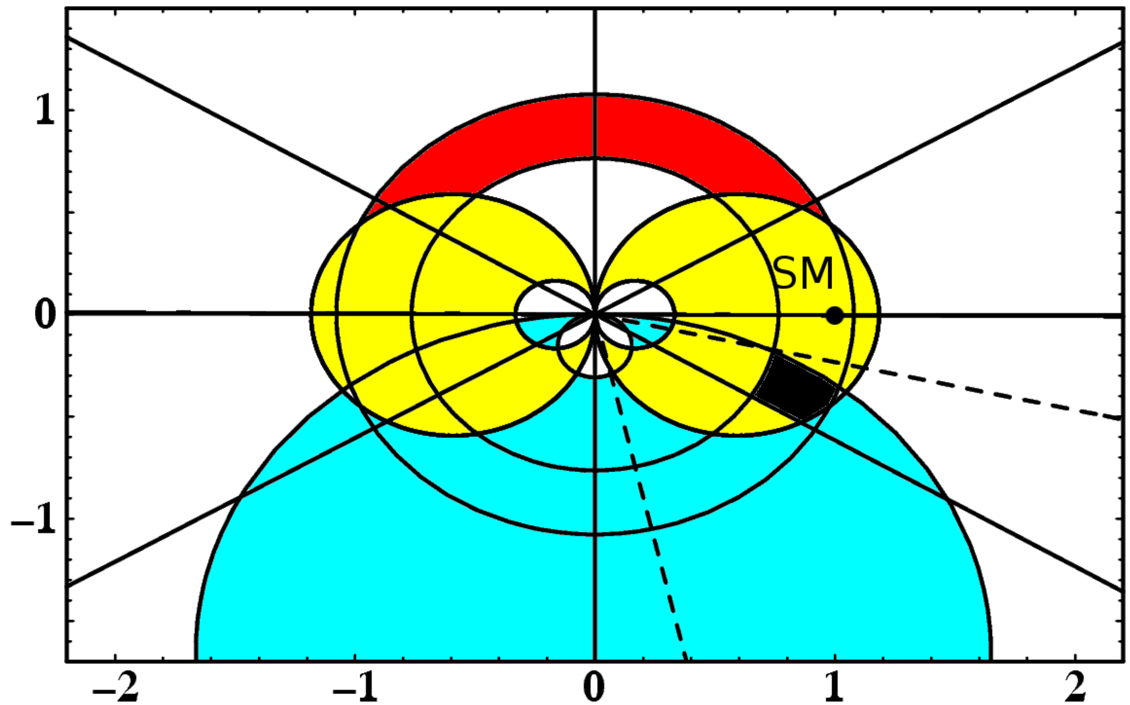
- BaBar, Belle and CLEO : $A_{\mathrm{SL}}^d = +0.0011 \pm 0.0055$
- So one gets $A_{\mathrm{SL}}^s = -0.013 \pm 0.015$
  (Grossmann et al., hep-ph/0605028)

Model independent approach – III



- Correlation between A^s_{SL} and $S_{\psi\phi}$
- D0 measurememt prefers the negative A^s_{SL}, so that positive $S_{\psi\phi}$ (with large exp. error)
- SM prediction : $S_{\psi\phi} = (0.038 \pm 0.003)$
- Still plenty room for the CPV in $b \to s$ transition

Lenz and Nierste



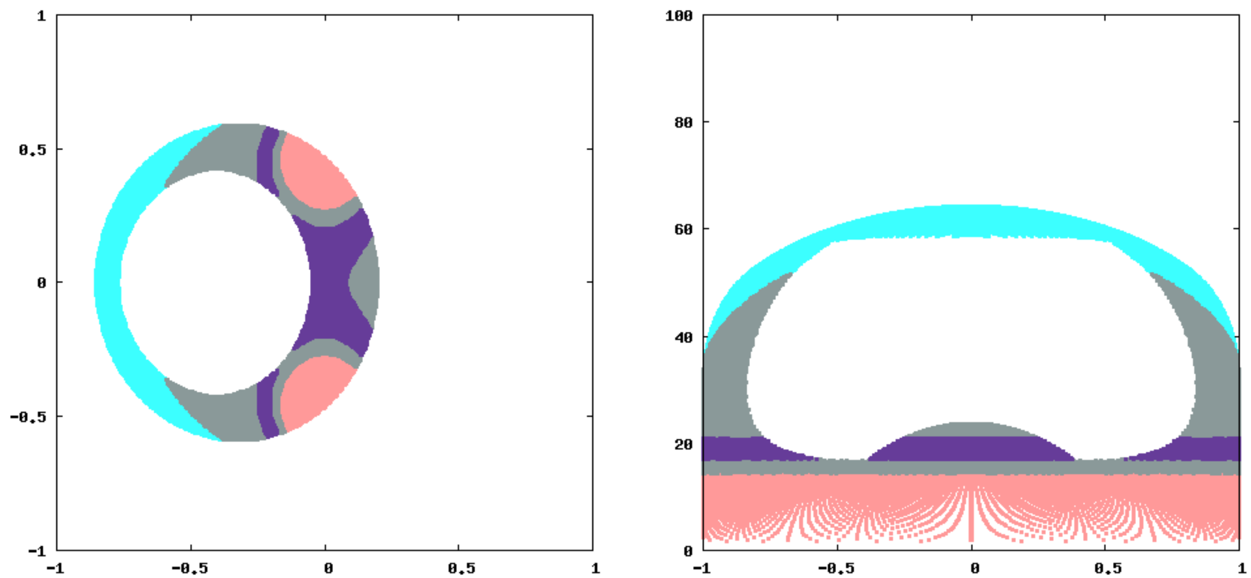
- $M_{12} \equiv M_{12}^{\rm SM} \Delta_s, \quad \Delta_s \equiv |\Delta_s| e^{0\phi_s^\Delta}$
- $\Delta M_s = \Delta M_s^{\rm SM} |\Delta_s|$, etc.
- SM prediction : $S_{\psi\phi} = (0.038 \pm 0.003)$
- Still plenty room for the CPV in $b \to s$ transition

$B_s - \overline{B_s}$ 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

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

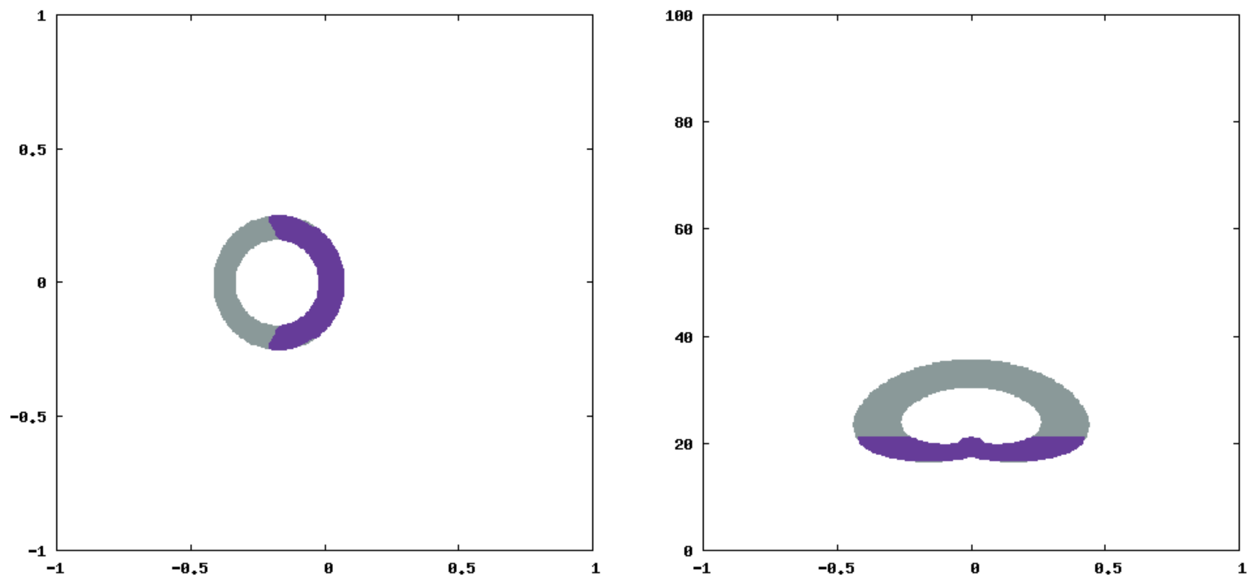
- $m_{\tilde{q}} = m_{\tilde{g}} = -\mu = 350$ GeV for $\tan\beta$ = 3



- $\Delta M_s > 14.4$ ps^{-1} for a cyan region
- 17 ps^{-1} < ΔM_s < 21 ps^{-1} for a blue region,
- Lightest down-type squark mass squared > (100 GeV)^2
- A transparent red mask is imposed over the region where lightest down-type squark mass squared > (200 GeV)^2

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

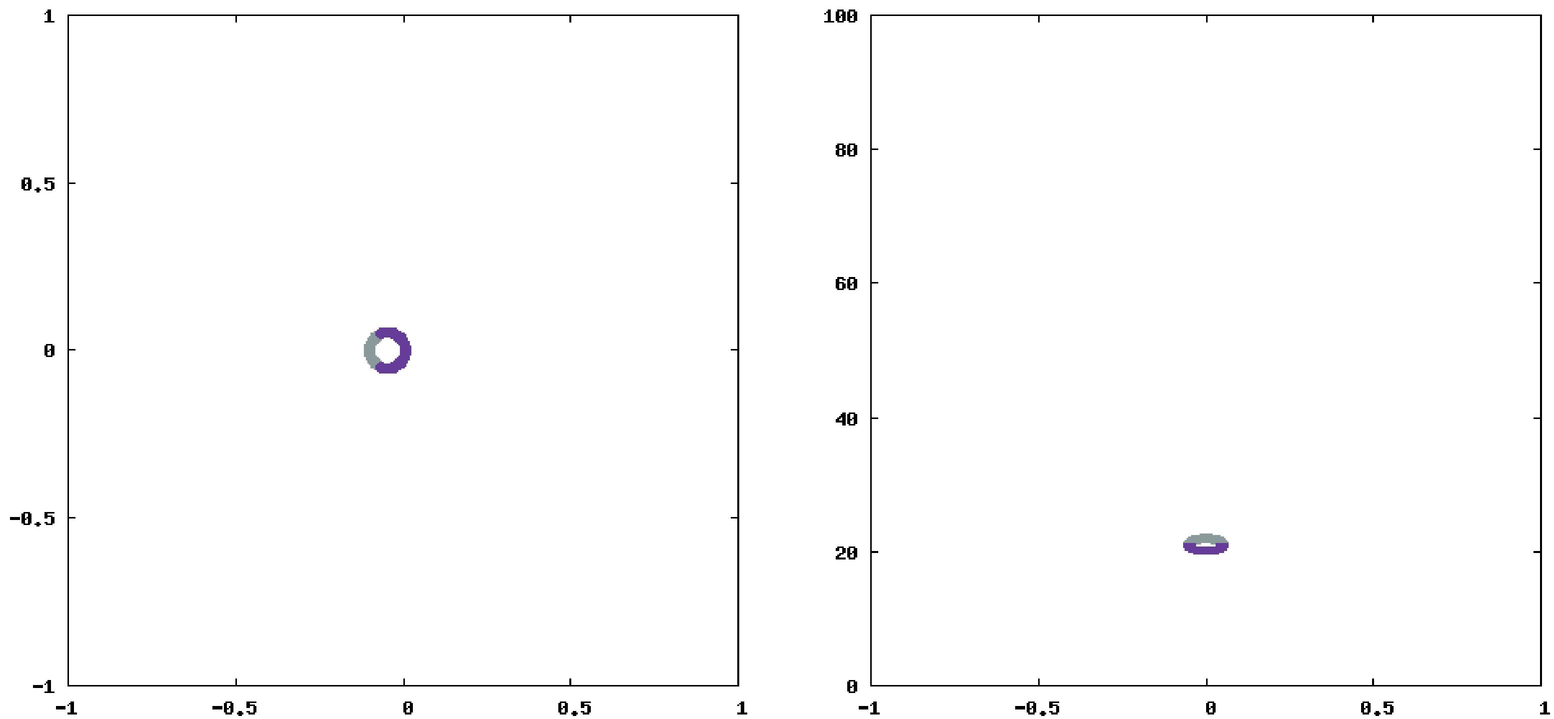
- $m_{\tilde{q}} = m_{\tilde{g}} = -\mu = 350$ GeV for $\tan\beta$ = 10



- $\Delta M_s > 14.4$ ps^{-1} for a cyan region
- 17 ps^{-1} < ΔM_s < 21 ps^{-1} for a blue region,
- Strongly constrained $(\delta^d_{23})_{LL}$ mixing, mainly by $B \to X_s\gamma$

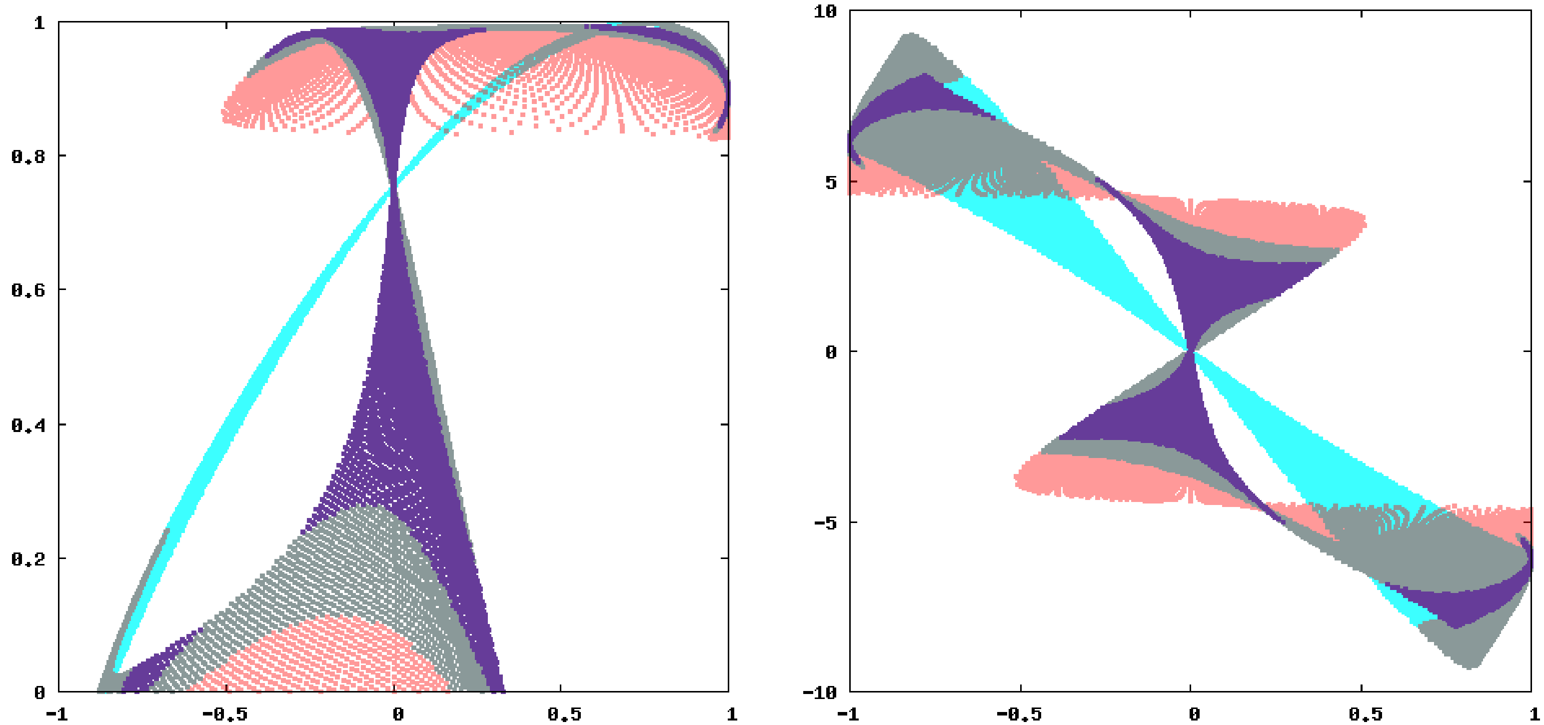
LL **insertion** ($\tan\beta = 40$)

- $m_{\tilde{q}} = m_{\tilde{g}} = -\mu = 350$ GeV for $\tan\beta$ = 40



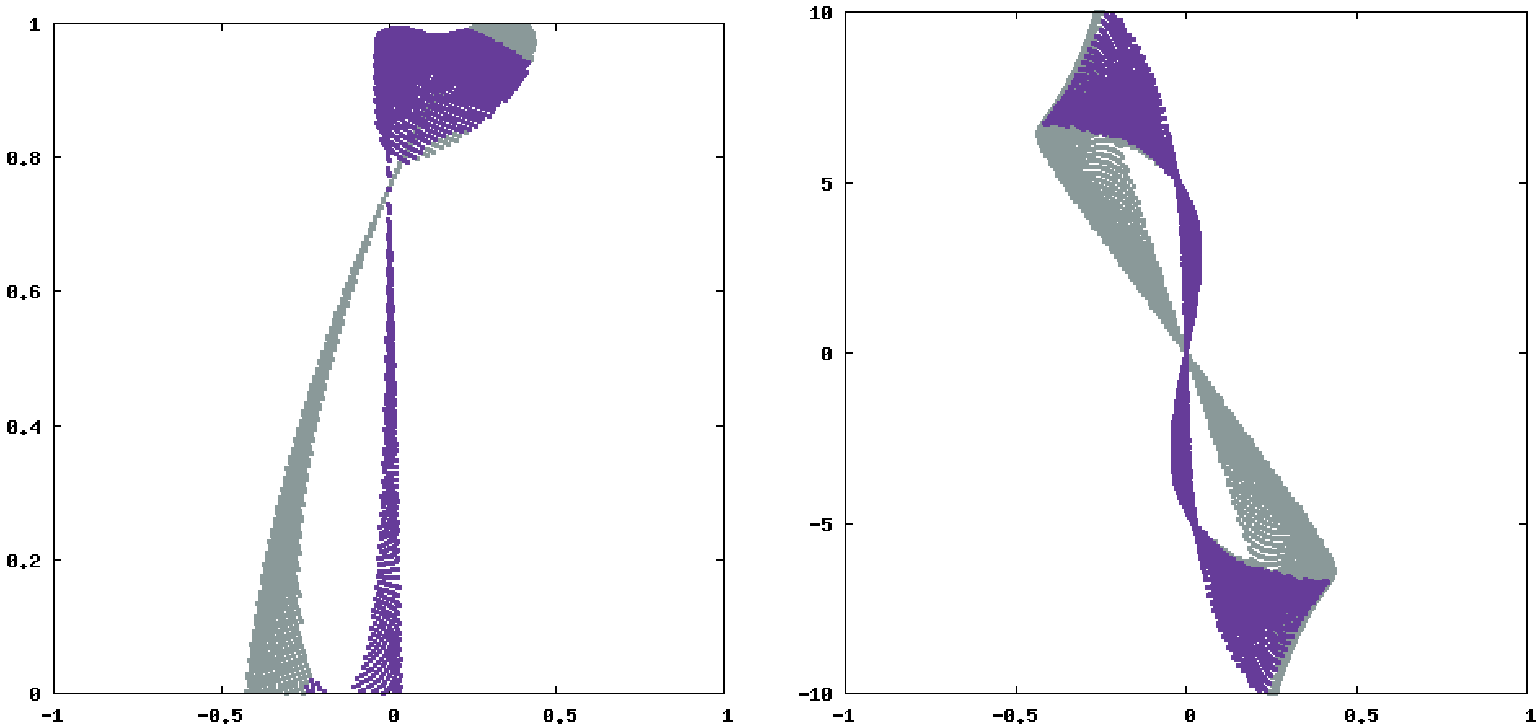
- The constraint even stronger for large $\tan\beta = 40$ due to the induced LR or RL mixing through double mass insertion
(Baek, Jang, Ko and Park, PRD 117701 (2000))

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



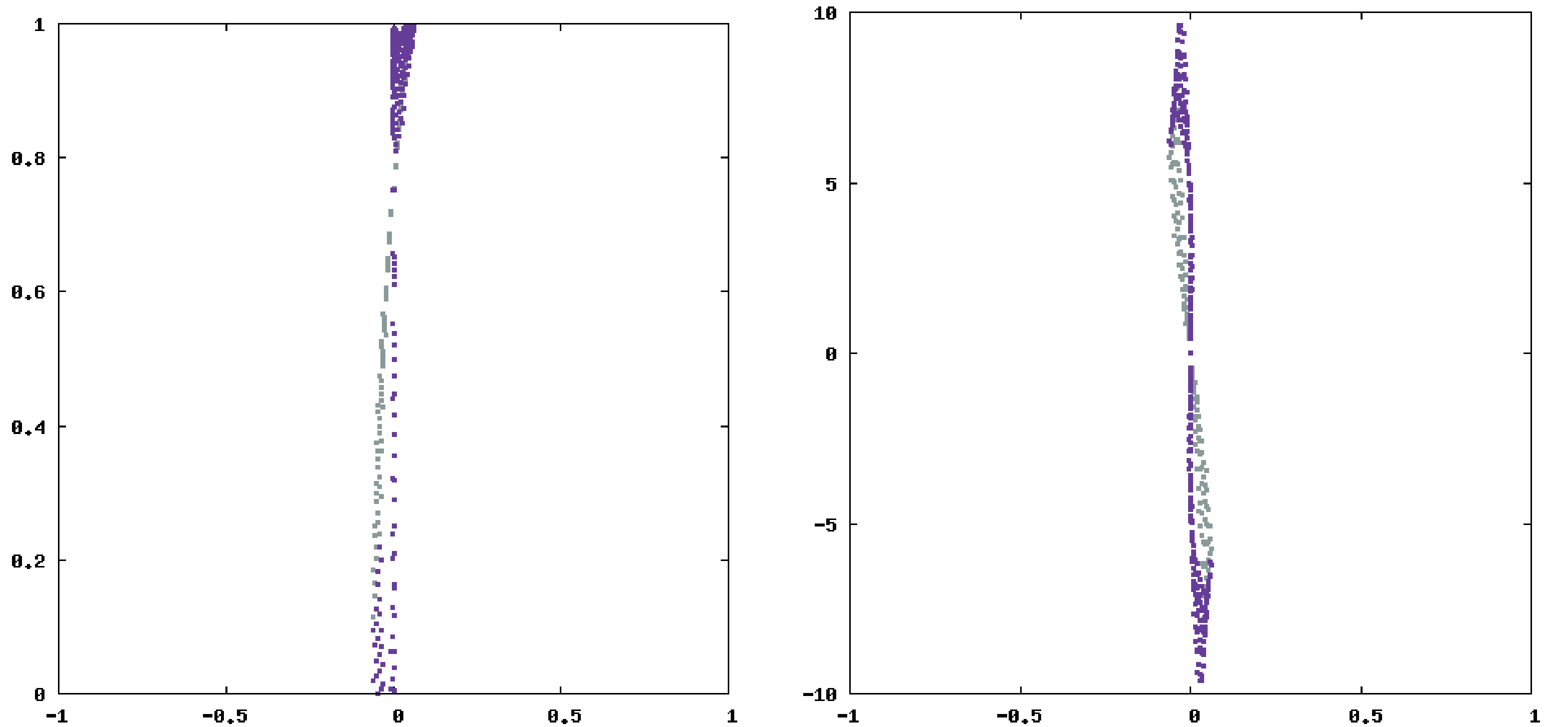
$S_{\phi K}$ vs $S_{\psi\phi}$ and $A_{\rm CP}$ vs. $S_{\psi\phi}$

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



$S_{\phi K}$ vs $S_{\psi\phi}$ and $A_{\rm CP}$ vs. $S_{\psi\phi}$

LL insertion ($\tan\beta = 40$)



$S_{\phi K}$ vs $S_{\psi\phi}$ and A_{CP} vs. $S_{\psi\phi}$

- So we demonstrated that there still could be large deviations from the SM predictions in the CP asymmetries in $B_s \to J/\psi\phi$ (through the phase of $B_s - \overline{B_s}$ mixing), $B \to X_s\gamma$, $B \to \phi K_s$
- All of these should be measured and compared with the SM predictions, in order to complete the test of CKM paradigm
- Many of them can be done only at Super B, and not at LHC
- Important to have a next generation B factory that has sensitivity to study these observables in detail

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,

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

- $(\delta^d_{LL})_{23} \simeq 9 \times 10^{-3}$ 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 $S_{\phi K}$

Implications for SUSY flavor models

- Alignment of quark and squark mass matrices can be achieved by flavour symmetries ($U(1), S_3$,....)

	Model	LL	RR	
A	LNS1	λ^2	λ^4	$LL \gg RR$
	NS,Moroi a	λ^2	1	$LL \ll RR$
	Moroi b	λ^2	$\lambda^{1/2}$	$LL \ll RR$
B	BHRR, PT b	λ^2	λ^2	$LL = RR$
	[?]	λ^3	λ^5	$LL \gg RR$
	PS	λ^2	λ^4	$LL \gg RR$
B+C	PT a	λ^2	λ^2	$LL = RR$
C	CKN	λ^2		$LL \gg RR$

- A:alignment, B:non-abelian, C:heavy squarks
- Some models are now excluded by $B_s - \overline{B_s}$ mixing

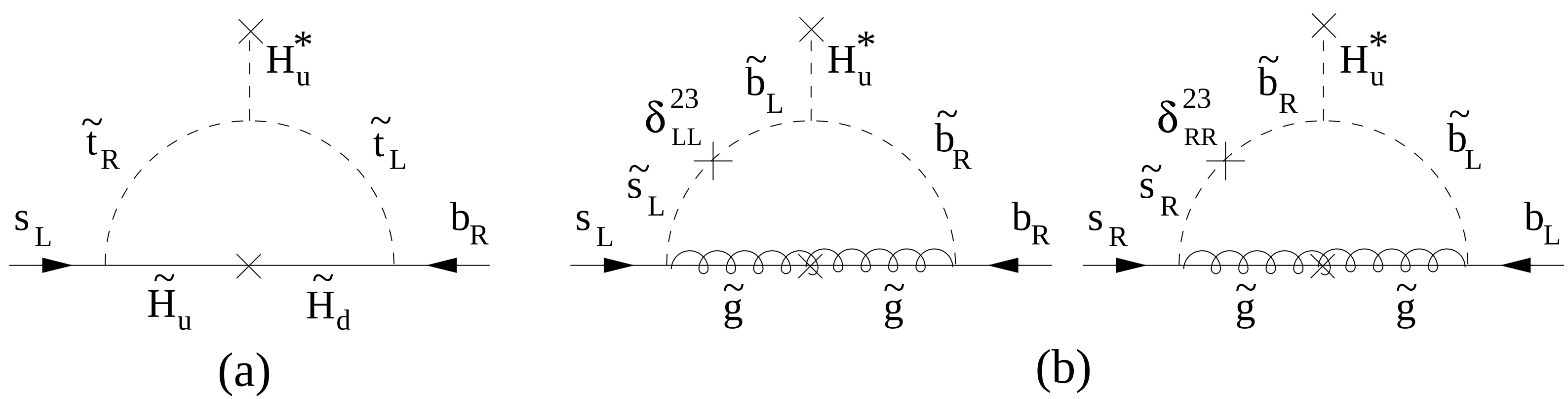
LR mixing: slow decoupling of heavy sparticles

- $B_s - \overline{B_s}$ mixing does not give a significant constraint on LR or RL mixing, which is less than 10^{-2}
- Still one can have large effects on $B \to X_s \gamma$ or $B_d \to \phi K_s$ CP asymmetries
- For LR or RL mixing, super B factory could be more sensitive to heavy sparticle effects than LHC
- Heavy squarks and gluinos are hard to study at LHC
- Their effects through quantum loop could affect B physics observables, such as CP asymmetries in $B \to \phi K_s$ or $B_d \to X_s \gamma$ through $LR(RL)$ mixing
- Super B could be more sensitive to heavy sparticles than LHC in some cases

$$B_s \longrightarrow \mu^+\mu^-$$

$B_s \to \mu^+\mu^-$ in SM and MSSM-I

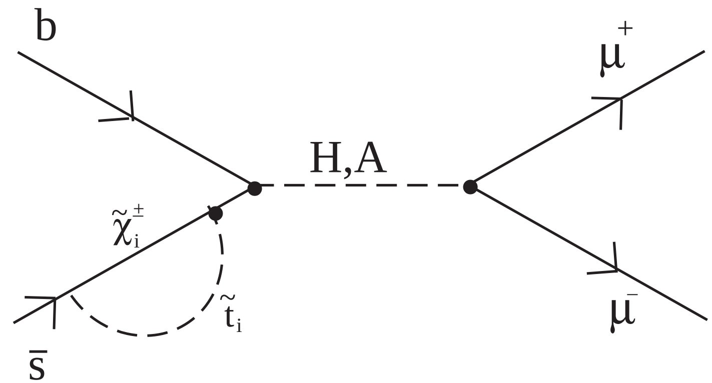
- SM prediction: $(3.7 \pm 1.2) \times 10^{-9}$ (very small) (W box and Z penguin diagrams)
- Current bound : $\lesssim 6 \times 10^{-8}$ from Tevatron
- MSSM Higgs sector is Type-II at tree level $\to$ Natural suppression of Higgs-mediated FCNC
- Loop corrections involving Soft SUSY breaking terms make it Type-III



- Higgs-mediated FCNC can be enhanced (e.g., $B_s \to \mu^+\mu^-$)

$B_s \to \mu^+\mu^-$ in SM and MSSM-II

- A typical diagram:



- $$C_S \propto \tan^3\beta \left(\frac{m_b\mu}{M_A^2}\right) \frac{\sin 2\theta_{\tilde{t}}}{2} f(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2, \mu^2)$$

  $\longrightarrow$ Need a large LR mixing in the stop sector, light stop and neutral Higgs bosons for enhanced C_S

- $a_\mu \propto \mu \tan\beta \longrightarrow$ Strong correlation between a_μ and $Br(B_s \to \mu^+\mu^-) \propto \tan^6\beta$ in mSUGRA (Dedes, Dreiner and Nierste)

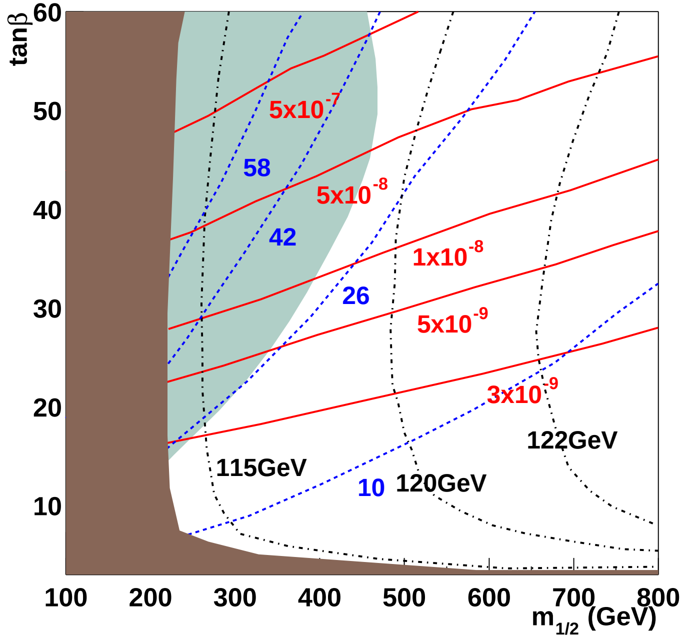
$B_s \to \mu^+\mu^-$ in SM and MSSM-III

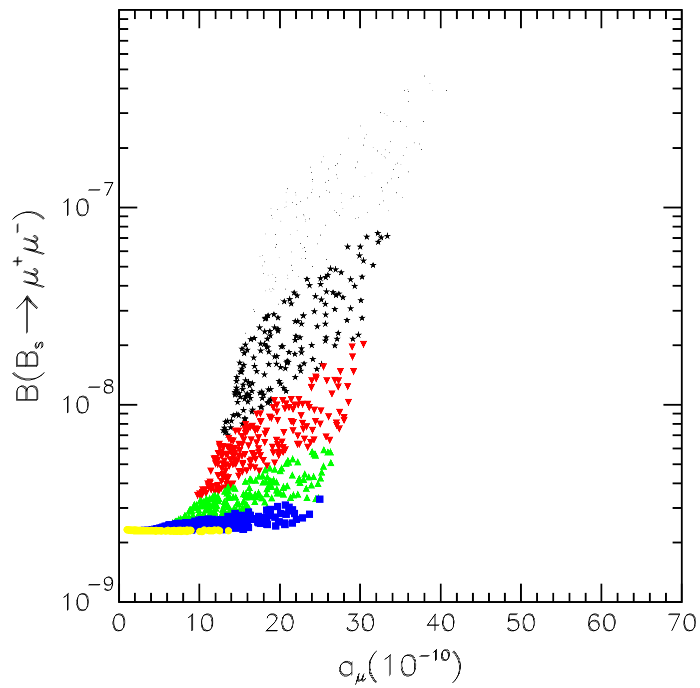
- General : Choudhury and Gaur ; Babu and Kolda ; C.S. Huang et al. ; Bobeth et al. ; Isidori and Retico ; Dedes and Pilaftsis, ...
- mSUGRA : Dedes, Dreiner, Nierste ; Arnowitt, Dutta, Kamon, Tanaka,...
- In other scenarios : Baek, Ko, Song ; Kane, Kolda, Lennon ; Tata et al ; Blazek et al ; Dermisek et al. ,....
- Correlation with the DM detection rates : Baek, Kim, Ko ; Baek, Cerdeno, Kim, Ko, Munoz ; Ellis, Olive,....

$B_s \to \mu^+\mu^-$: Cont'd

- $B_s \to \mu^+\mu^-$ can be enhanced, if
  - Large A_t for a large $\tilde{t}_L - \tilde{t}_R$ mixing
  - Large $\tan\beta$
  - Light neutral Higgs bosons
- If $A = 0$ at the messengger scale,
  then we need a high messenger scale $M_{\rm mess}$
  in order to generate a large enough A_t from the RG running
- GMSB with low $N_{\rm mess}$ and low $M_{\rm mess}$ do not have a large Br. for $B_s \to \mu^+\mu^-$ to be observed at the Tevatron Run II
- Similarly for AMSB,.....

mSUGRA

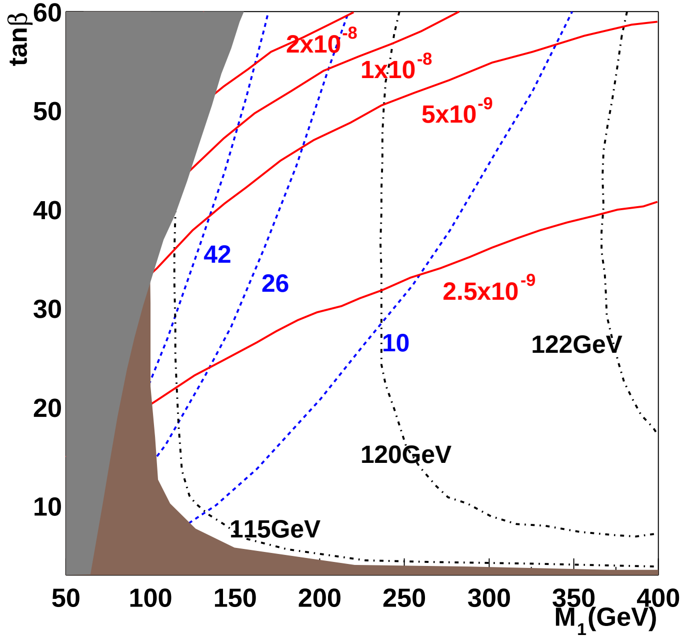


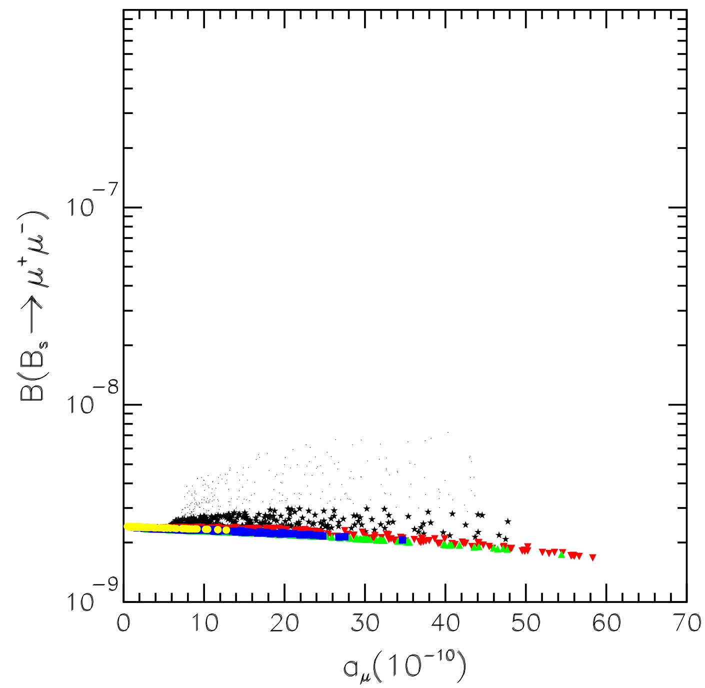


$m_0 = 300$ GeV and $A_0 = 0$ GeV

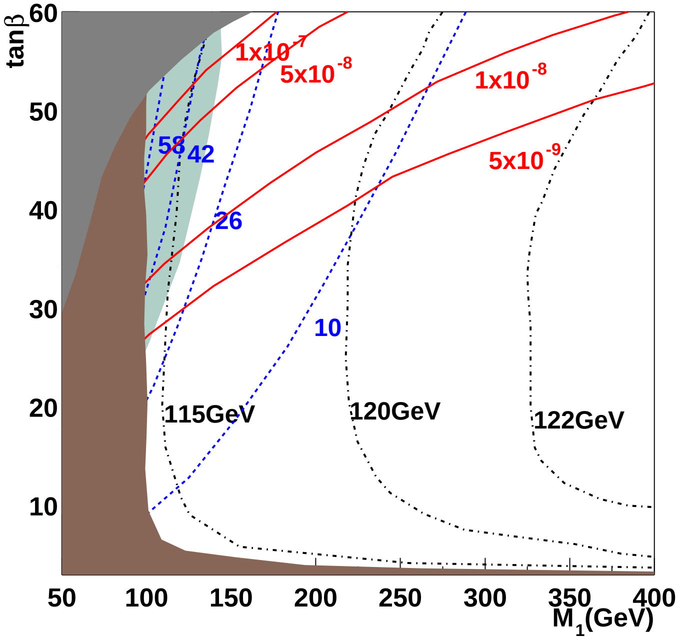
$\tan\beta$ color codes : <10, $10-20$, $20-30$, $30-40$, $40-50$, $50-60$

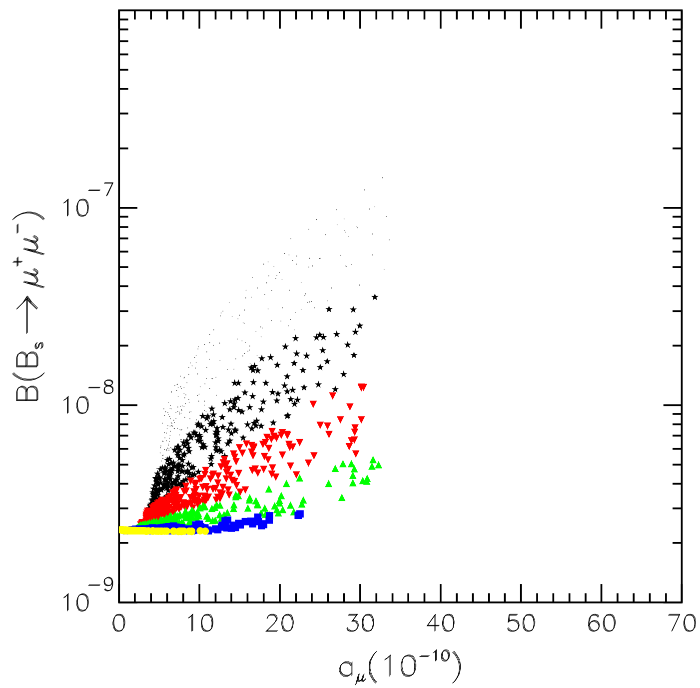
GMSB : $N_{\text{mess}} = 1$ and $M_{\text{mess}} = 10^6$ GeV



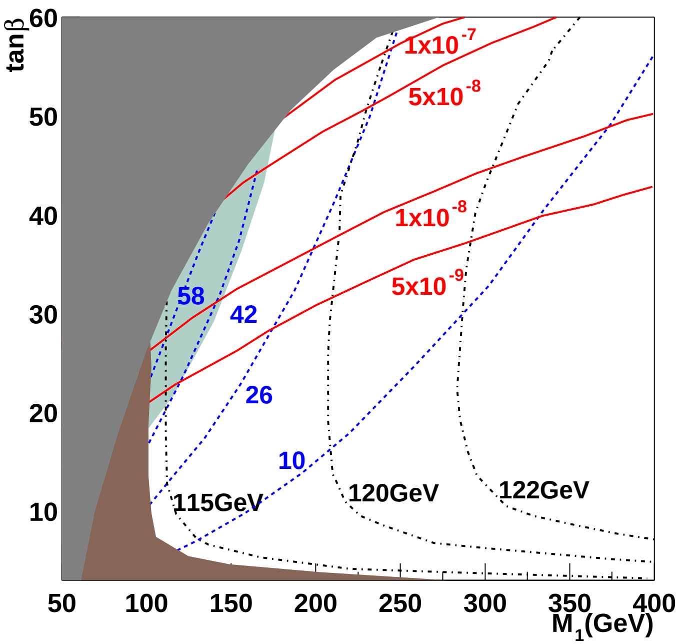


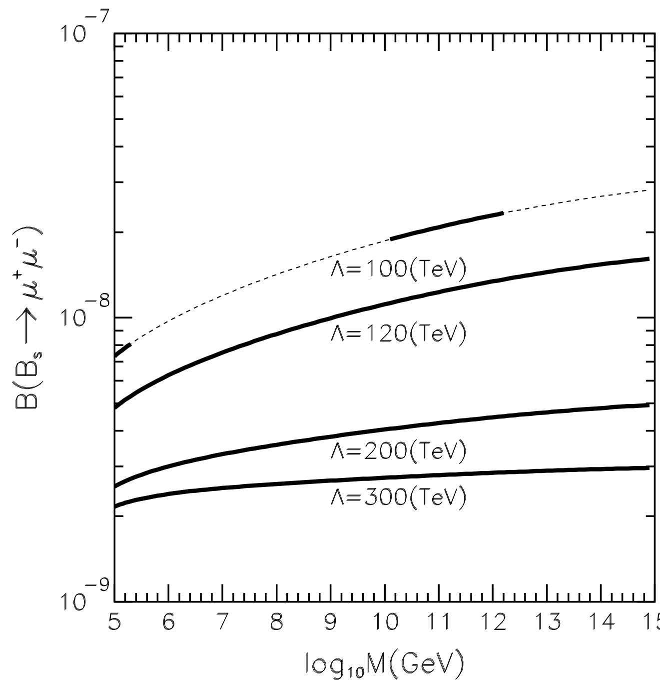
GMSB : $N_{\text{mess}} = 1$ and $M_{\text{mess}} = 10^{15}$ GeV





GMSB : $N_{\mathrm{mess}} = 5$ and $M_{\mathrm{mess}} = 10^{15}$ GeV





If $B_s \to \mu^+\mu^-$ is observed with $B > 2 \times 10^{-8}$, then low M_{mess} and N_{mess} GMSB, AMSB, no-scale SUGRA,... are all excluded without direct discovery of SUSY particles.

Neutralino DM Scattering and $B_s \to \mu^+\mu^-$-I

w/ S. Baek and Y.G.Kim , JHEP **0502**, 067 (2005)

- WMAP : $\Omega_{\rm DM} h^2 = 0.1126^{+0.0161}_{-0.0181}$,
  $\to 0.095 < \Omega_{\rm CDM} h^2 < 0.129$ (2 σ)
- SUSY models with R-parity $\to$ LSP is a DM candidate
- DAMA experiment : $\sigma_{\chi p} \sim 10^{-5} - 10^{-6}$ pb
  Now excluded by CDMS II, down to $10^{-7} - 10^{-6}$ pb
- Consider Neutralino (χ^0) DM within general SUGRA models in a parameter space where it can be enhamced upto the sensitivity region of DAMA and CDMS II

Neutralino DM Scattering and $B_s \to \mu^+\mu^-$-II

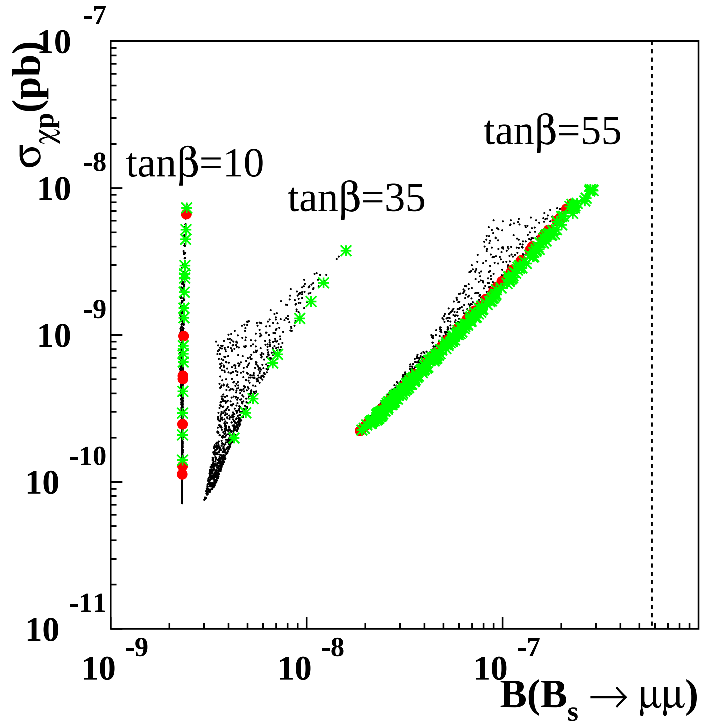
- $\sigma_{\chi p}$ is dominated by Higgs exchange in the large $\tan\beta$ region $\to \sigma_{\chi p} \propto \tan^2\beta / m_A^4$
- Remember $B(B_s \to \mu^+\mu^-) \propto \tan^6\beta / m_A^4$
- Large DM scattering x-section $\longrightarrow$ Large $B(B_s \to \mu^+\mu^-) \longrightarrow$ Conflict with the CDF/D0 data
- Important equations to remember :

$$\mu^2 = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1} - \frac{1}{2} M_Z^2,$$

$$m_A^2 = m_{H_u}^2 + m_{H_d}^2 + 2\mu^2 \simeq m_{H_d}^2 + \mu^2 - M_Z^2/2$$

$\longrightarrow$ Lower μ implies the Higgsino component of LSP increases, and lighter m_A

mSUGRA $m_0 = 300$ GeV and $A_0 = 0$ GeV

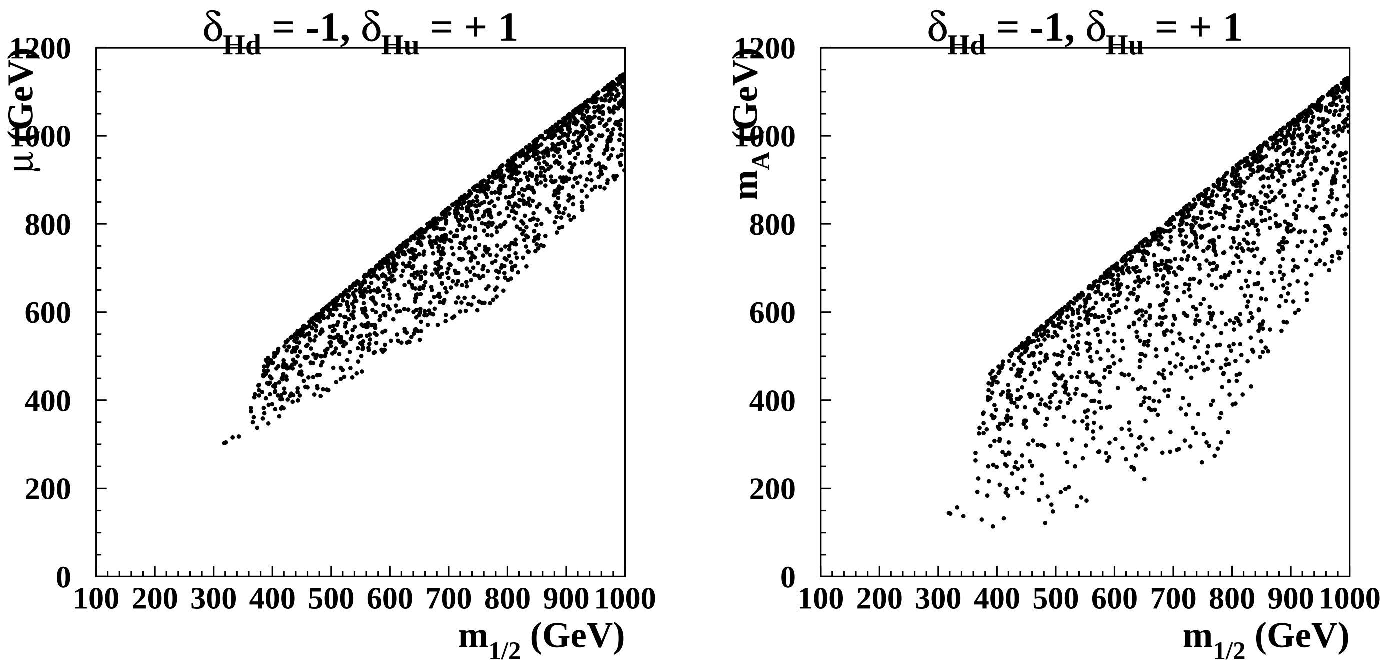


Less than, within, Greater than 2 σ of WMAP,

- $\sigma_{\tilde{\chi}p} \lesssim 10^{-8}$ pb AND $B(B_s \to \mu\mu) \lesssim 3 \times 10^{-7}$
- Typically μ is large in mSUGRA $\to$ Binolike LSP and heavier m_A leading to suppression of these observables

Nonuniversal Higgs mass parameters - I

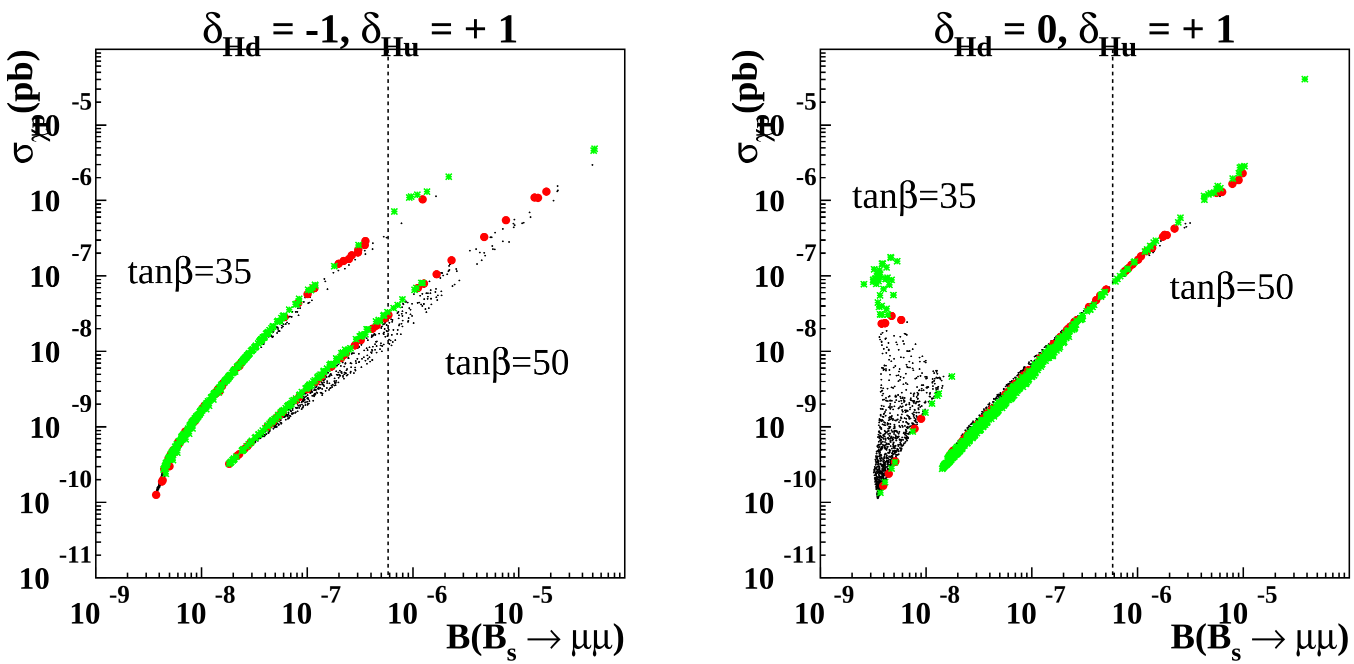
- Allow nonuniversal Higgs mass parameters:
  $m^2_{H_u} = m^2_0(1+\delta_{H_u})$ and $m^2_{H_d} = m^2_0(1+\delta_{H_d})$



- Lower $\mu \to$ Larger Higgsino component in LSP and Lighter $m_A \to$ Enhanced DM scattering cross section (Cerdeno, Munoz, et al.)

Nonuniversal Higgs mass parameters - II

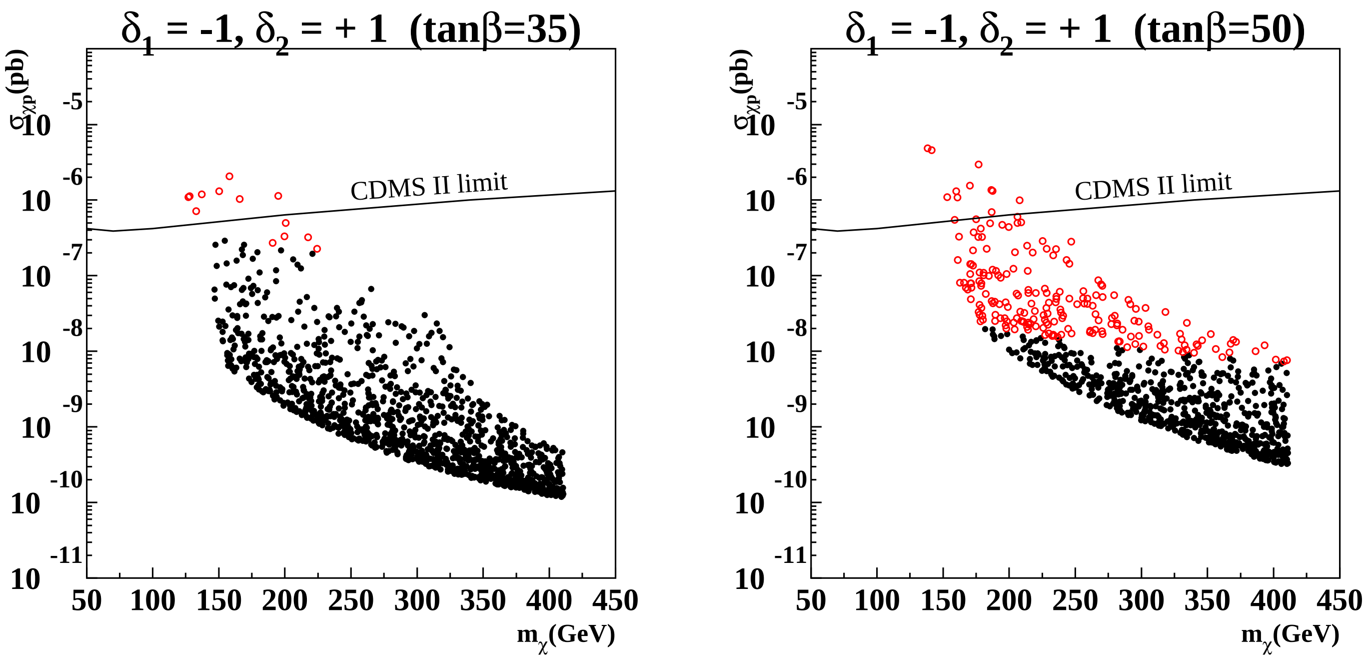
- Enhanced DM scattering cross section



- Strongly constrained by $B(B_s \to \mu^+\mu^-) < 5.8 \times 10^{-7}$
- Essentially DAMA region ($\sigma > 10^{-6}$ pb) is excluded, before CDMS did !
- Even stronger by new data $< 6 \times 10^{-8}$!

Nonuniversal Higgs mass parameters - III

- $B(B_s \to \mu^+\mu^-)$ stronger than CDMS bound :



- Strongly constrained by $B(B_s \to \mu^+\mu^-) < 5.8 \times 10^{-7}$
- $B(B_s \to \mu^+\mu^-)$: Important constraint on DM scattering
- B physics complementary to direct search for SUSY particles

B physics within EWBGEN MSSM

EW baryogenesis and B Physics (I)

[S. Baek and P. Ko, PRL **83**, 488 (1999)]

- Baryon No. Asymmetry in the Universe :
  $\frac{n_B}{s} \simeq 4 \times 10^{-12}$
- Sakharov's Critera for Baryogenesis :
  - B Violating Interactions
  - C and CP violations
  - Out of thermal Equilibrium
- SM meets Sakharov's criteria, but need too light Higgs which has been already excluded by LEP experiments

EW baryogenesis and B Physics (II)

Carena, Wagner; Cline et al.;.....

MSSM : OK, but now the margin is getting narrower

- Many new CP violating phases
- μ phase is most important, but is strongly constrained by e/n EDM's
  Assume that 3rd generation squarks and charginos are light
  with new CP violating phases in μ and A_t
- First order phase transition for relatively light Higgs (but the LEP bound on m_h is getting tight now)
  This can be less serious in extended models (NMSSM, extra U(1), etc.)
- Another way to check this scenario by observing the effects of the μ phase : CP violations in B, K system and Collider Signals

EW baryogenesis and B Physics (III)

- The chargino mass matrix in the MSSM :

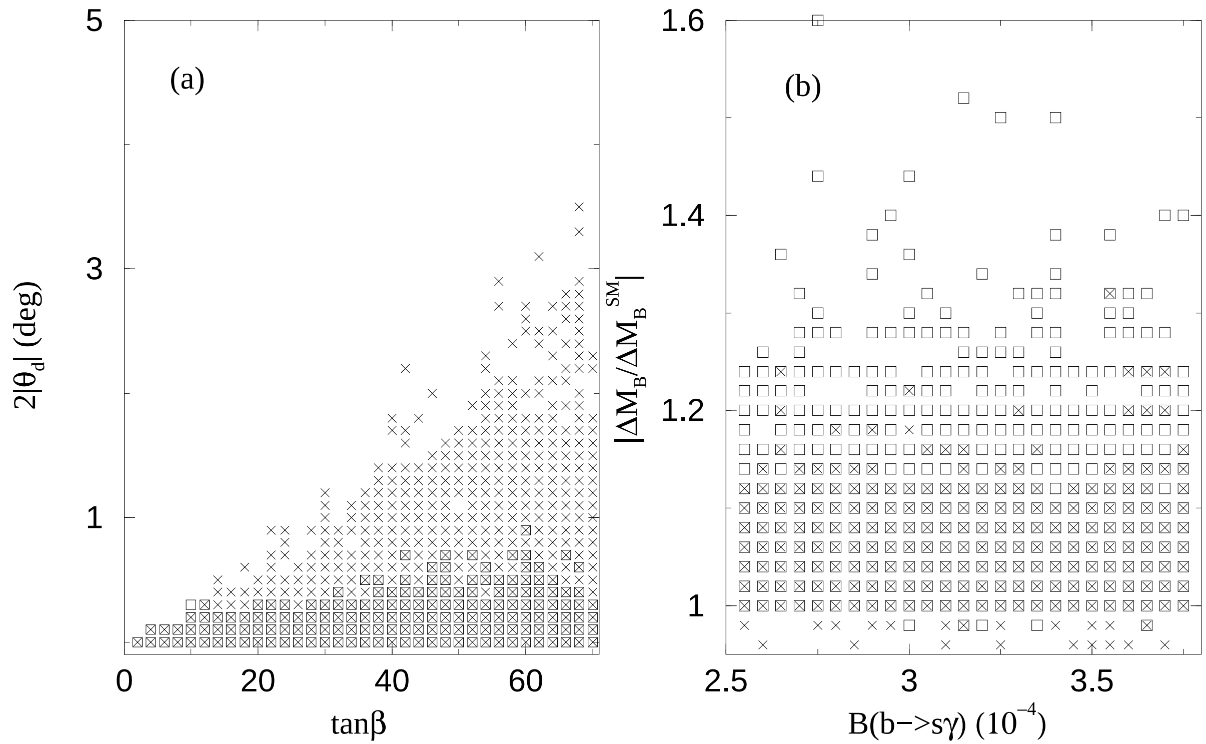
$$M_{\chi^\pm} = \begin{pmatrix} M_2 & \sqrt{2} m_W \sin\beta \\ \sqrt{2} m_W \cos\beta & \mu \end{pmatrix}.$$

- The stop mass matrix :

$$M_{\tilde{t}}^2 = \begin{pmatrix} m_Q^2 + m_t^2 + D_L & m_t (A_t^* - \mu / \tan\beta) \\ m_t (A_t - \mu^* / \tan\beta) & m_U^2 + m_t^2 + D_R \end{pmatrix},$$

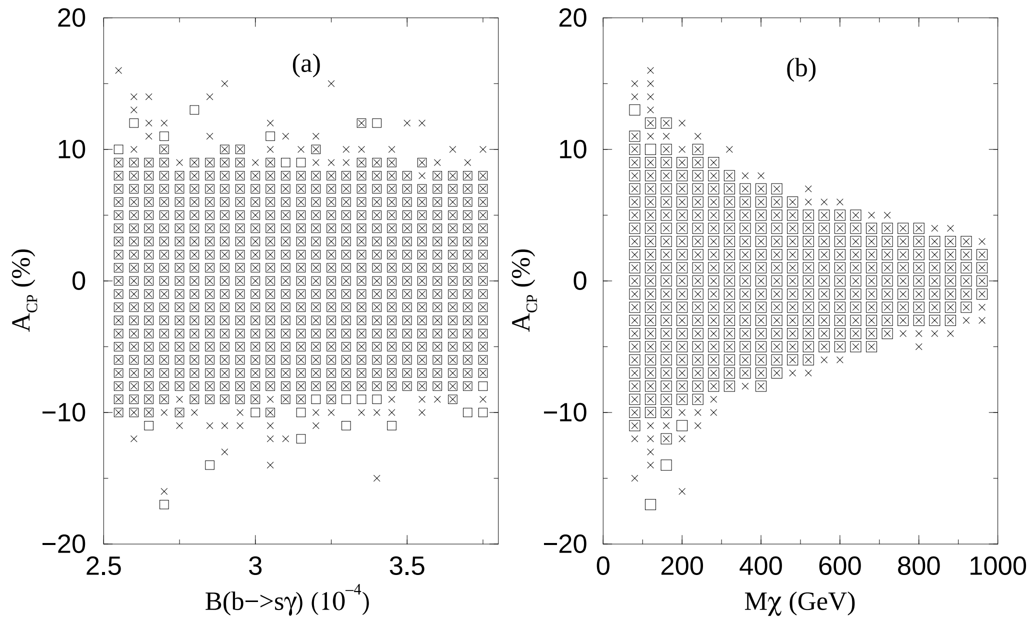
- Two new phases in this matrix, $\mathrm{Arg}(\mu)$ and $\mathrm{Arg}(A_t)$ (M_2 : real)
  $\longrightarrow$ New CP violatiog phenomena in the B system
  cf. NLC can measure μ phase, M_2, etc..(S.Y.Choi et al.)

EW baryogenesis and B Physics (IV)



- ΔM_{B_d} can be enhanced upto $\sim 80\%$ compared to the SM prediction
- No new phase shists in $B_d - \overline{B}_d$ and $B_s - \overline{B}_s$: Time dependent CP asymmetries in $B_d \to J/\psi K_S$ still measures the KM angle $\beta = \phi_1$

EW baryogenesis and B Physics (V)



(also Aoki and Oshimo)

- $|A_{\rm CP}^{b\to s\gamma}| \lesssim 16\%$ Large deviation from the SM prediction cf. Belle data (Nakao's talk at LP03) :
  $-0.107 < A_{\rm CP}^{b\to s\gamma} < 0.099$ (90 % CL)
- $B(B \to X_s \mu^+\mu^-)$ can be enhanced upto 80 %
- ϵ_K can differ from the SM value by $\sim 40\%$

Summary Table

Possible effects of the phase of μ necessary for EWBGEN, and the phase of δ_{i3}^{d} (with $i = 1, 2$)

Observables	$\mathrm{Arg}(\mu)$	$\mathrm{Arg}(\delta_{i3}^{d})$	SuperB	LHC
ΔM_d	Y	Y	O	O
$\sin 2\beta$	N	Y	O	O
ΔM_s	Y	Y	X	O
$\sin 2\beta_s$	N	Y	X	O
$A_{\rm CP}^{b\to s\gamma}$	Y	Y	O	X
$A_{\rm CP}^{b\to d\gamma}$	Y	Y	O	X
$B \to X_s l^+ l^-$	Y	Y	O	X
$B \to X_s \nu \bar{\nu}$	Y	N	O	X
$B_d \to \phi K_S$	Y	Y	O	$O(?)$

SUSY GUT : LFV vs. B physics

Charmonium Spectroscopy

Newly observed charmonia

- $B \to X(3872)K \to (J/\psi\pi\pi)K$
- $e^+e^- \to J/\psi X(3940)$ and $X(3940) \to D\overline{D^*}$
- $B \to X(3945)K \to (J/\psi\omega)$ ($C = +$)
- $e^+e^- \to J/\psi X(4160)$ and $X(4160) \to D^*\overline{D^*}$
- $e^+e^- \to \gamma X(4260)$ and $X(4260) \to J/\psi\pi\pi$
- $e^+e^- \to \gamma X(4360)$ and $X(4360) \to \psi(2S)\pi\pi$
- $e^+e^- \to \gamma X(4660)$ and $X(4660) \to \psi(2S)\pi\pi$
- Decay rate, Br's, I^G, J^{PC}: not well known
- Nature of these states deserve more study
- $B \to J/\psi\pi$ has a little more phase space, although Cabbibo suppressed

Concluding Remarks

- As more data are accumulated, CKM paradigm is in better shape
- Room for new physics contributions to flavor and CP violations in the quark sector is getting tight
- Small effects may be there, but it would not be easy to disentangle them from the SM effect, considering various theoretical uncertainties and experimental errors
- Constraint on the model building: need universal soft terms such as GMSB, and flavor symmetry may not be good enough
- Flavor conserving CP phase (μ or A_t phase) may be still there, with effects on Higgs sector CP violation or $B \to X_s \gamma$ CP asymmetry

Concluding remarks-II

- However, large deviations still possible in some observables, some of them are sensitive to very heavy sparticles so that LHC cannot access
  CP asymmetries in $B_d \to \phi K_s$, $B \to X_{s(d)}\gamma$, $B_s \to J/\psi\phi$, and $B_s \to \mu^+\mu^-$
- Direct search at the LHC is much more useful to produce new particles (SUSY particles, here), but studying flavor and CP violation would not be so easy without low energy experiments
- Informations on flavor and CP violation from Tevatron and LHC will be important for unveiling nature of any new physics beyond the SM