Searching for New Physics in B decays

Yasuhiro Okada (KEK)

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New era of B physics

- Two B factory experiments Belle at KEKB and BABAR at PEP-II are very successful.
  (~340/fb at KEKB and ~250/fb at PEP-II)
- The asymmetric B factories provides measurements of time-dependent CP violations in B decays.
- In future, more B physics will come at hadron machines (Tevatron, LHCb) and upgrade of the current B factories as well as Super B Factory
  (5-10/ab/year).

Goals of future B physics

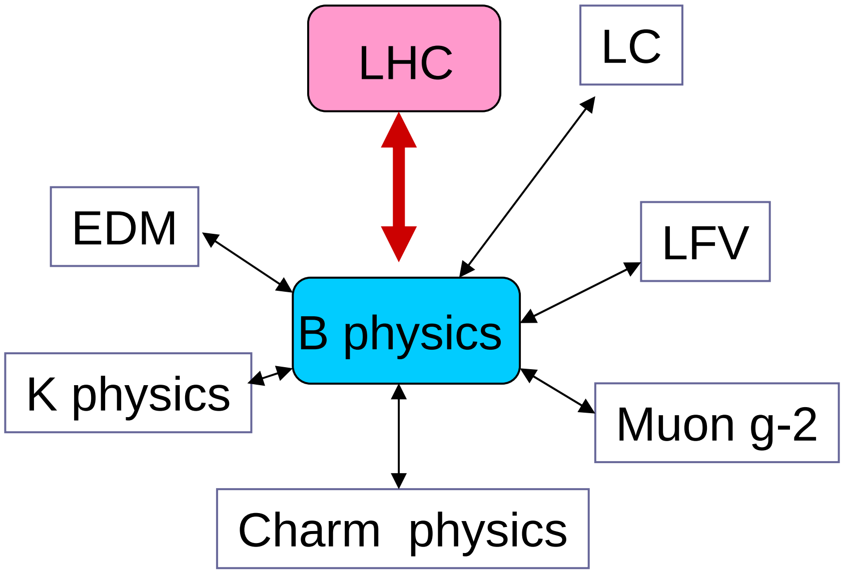
- Main purpose of B physics from now on is to search for new physics effects in flavor-mixing and CP violation.
- There are several ways to look for new physics in CP violation and rare B decay processes.
- In order to identify a new physics model, we need to know pattern of deviations from the SM predictions in various observables.

New Physics in LHC era

- Some signals of new physics may be obtained at early stage of LHC.

(SUSY, Large extra dim. etc)

- Important to consider impacts of B physics to LHC physics, and vice verse.
- In general, correlations among various areas are important to figure out what is new physics.



Content of this talk

- Various methods to look for new physics effects in B decays.
- Comparative study of B physics signals in three SUSY models. "SUSY loop effects"
- SUSY with minimal flavor violation (MFV) at a large tan β . "Higgs exchange"
- B physics signals of large extra dimension models

Super KEKB LoI

SLAC 10^36 study group

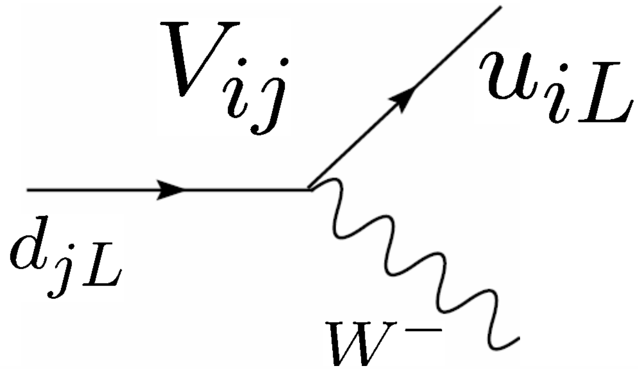
New Physics Searches in B decays

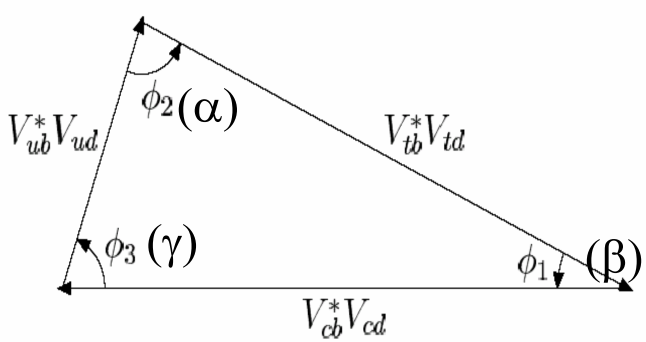
- There are may ways to look for new physics effects in B decays, both at Bd(Bu) and Bs experiments.

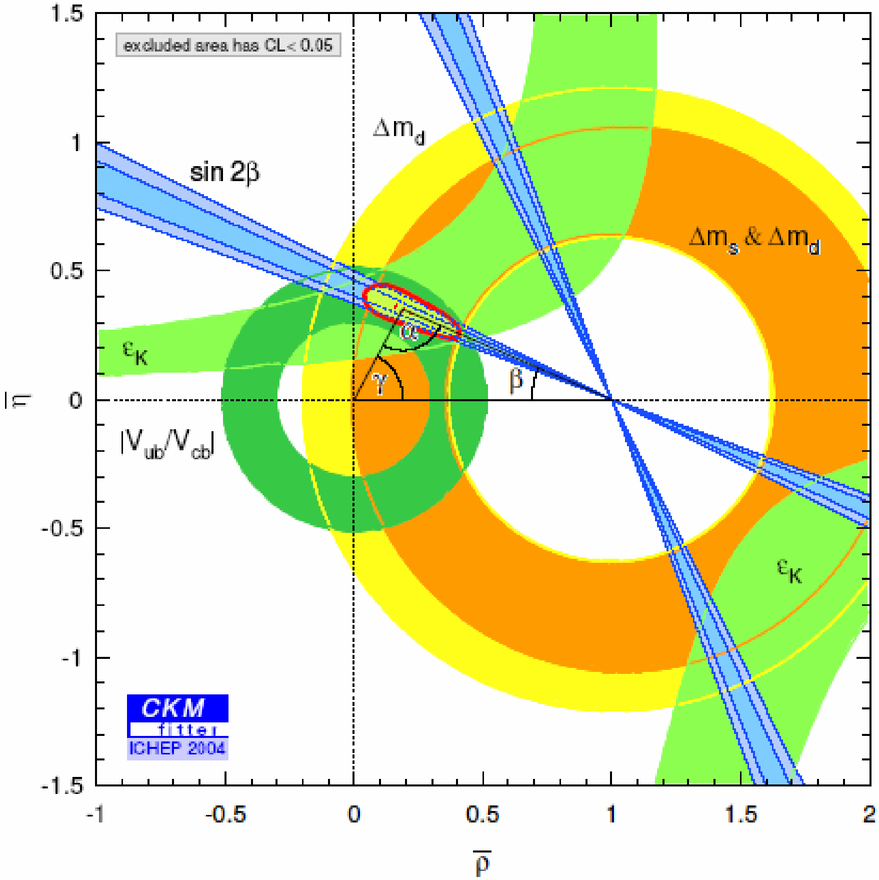
1. Consistency test of the unitarity triangle.
2. Comparison of various CP asymmetries.
3. Rare B decays.
4. Tau and charm physics at a Super B factory.

Unitarity triangle

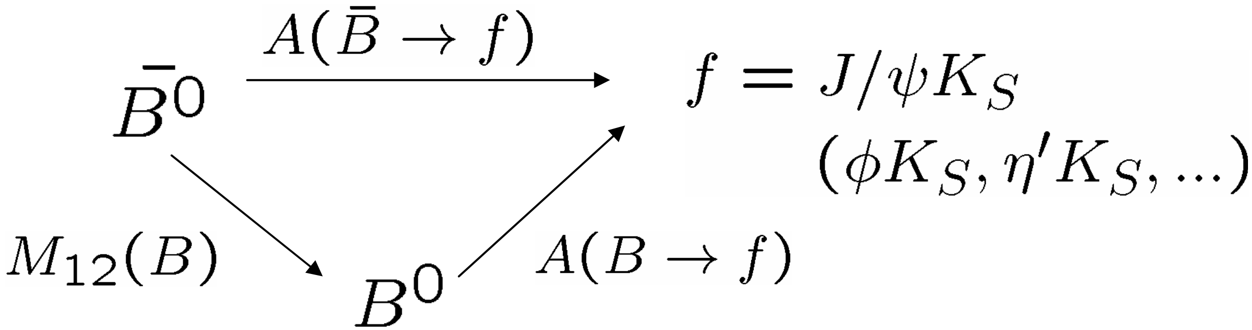
- In the SM, all flavor and CP phenomena can be explained by the Cabibbo- Kobayashi-Maskawa matrix.







Time-dependent CP asymmetry in B decays



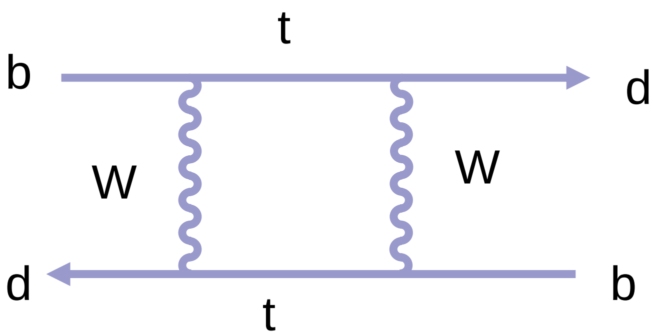
Time –dependent asymmetry can arise from the interference of two paths in the B-> f decay amplitude.

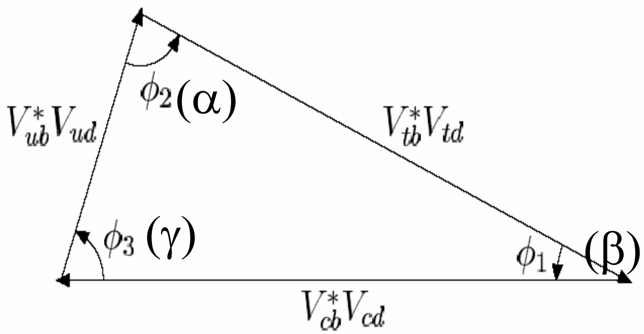
$$\frac{\Gamma(\bar{B}^0_{phys} \to f) - \Gamma(B^0_{phys} \to f)}{\Gamma(\bar{B}^0_{phys} \to f) + \Gamma(B^0_{phys} \to f)} = A_f \cos \Delta m t + S_f \sin \Delta m t$$

A_f : Direct CP asymmetry
S_f: Mixing –induced (Time-dependent) CP asymmetry

In the Standard Model, the B- B bar mixing amplitude have the phase 2ϕ_1

$$M_{12} \propto (V_{td}^* V_{tb})^2 \propto e^{2i\phi_1}$$





In general, the decay amplitude depends on several weak phases

$$A(B \to f) = \sum_k a_k e^{i\delta_k} e^{i\phi_k^W}$$

$$A(\bar{B} \to f) = \eta_f \sum_k a_k e^{i\delta_k} e^{-i\phi_k^W}$$

(η_f : CP eigenvalue of f)

If f is an CP eigen state, and the decay amplitude is dominated by one weak phase amplitude, then

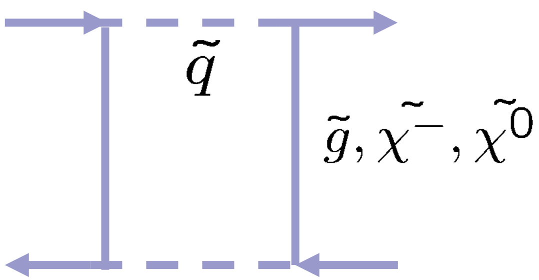
$$A_f = 0, S_f = -\eta_f \sin 2(\phi_1 + \phi^W)$$

New physics effects in B-B mixing

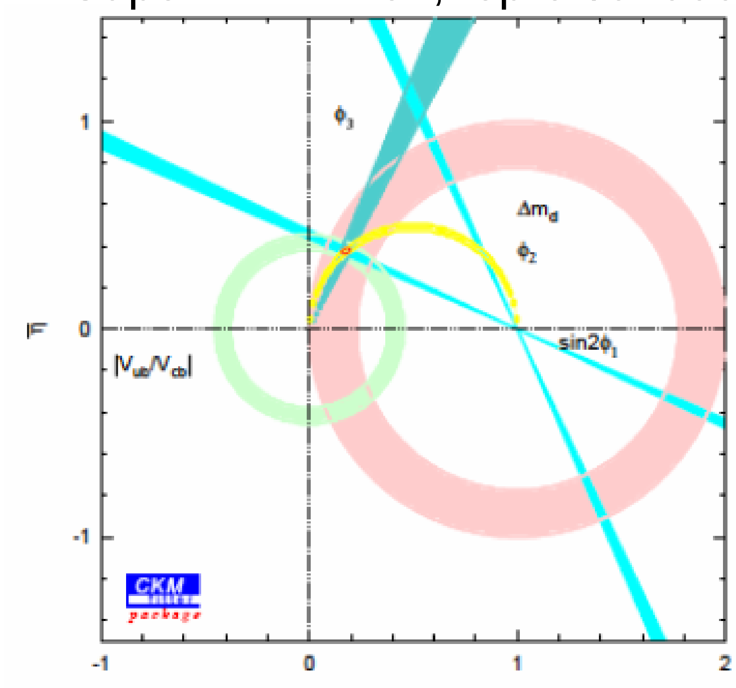
1. Bd-unitarity triangle

–> New contributions to the Bd mixing amplitude.

Ex. SUSY loop diagram



Super KEKB LoI ,hep-ex/0406071



Unitarity triangle at 50/ab

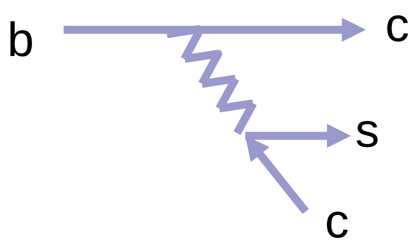
2. Bs mixing and CP asymmetry in Bs –>J/ψ ϕ

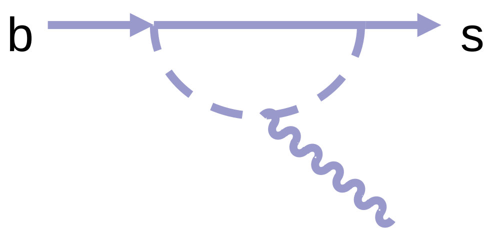
–> The magnitude and the phase of the Bs mixing amplitude.

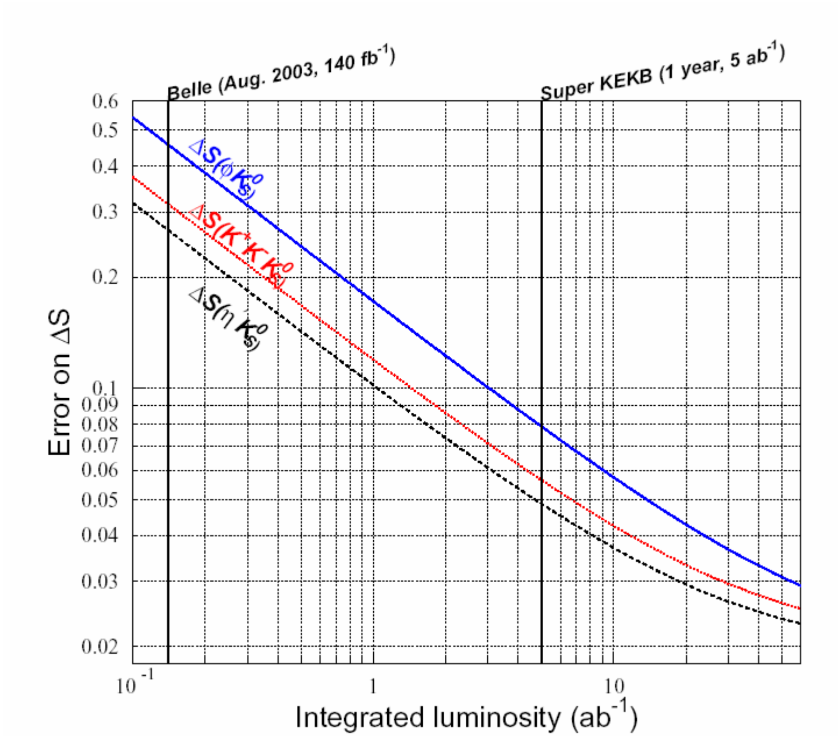
Comparison of various CP asymmetries

CP asymmetries from B –>J/ψKs, B –>φKs, B –>η'Ks.

–> A new CP phase in the b-s-g amplitude. These should be the same in the SM.







In order to confirm the anomaly of b-s transition, we need a large luminosity (>a few /ab)

Rare B decays

Direct CP violation in b->s γ. (New phase in b-s-γ)

$$A_{CP} = \frac{B(b \to s\gamma) - B(\bar{b} \to s\gamma)}{B(b \to s\gamma) + B(\bar{b} \to s\gamma)}$$

|Acp|<1% in SM

Mixing induced CP violation in B->Msγ. (b->sγ_R)

$$A_{CP}^{mix}(B \to K^*\gamma) = \frac{2Im(e^{-i\phi_M}C_7C_7')}{|C_7|^2 + |C_7'|^2}$$

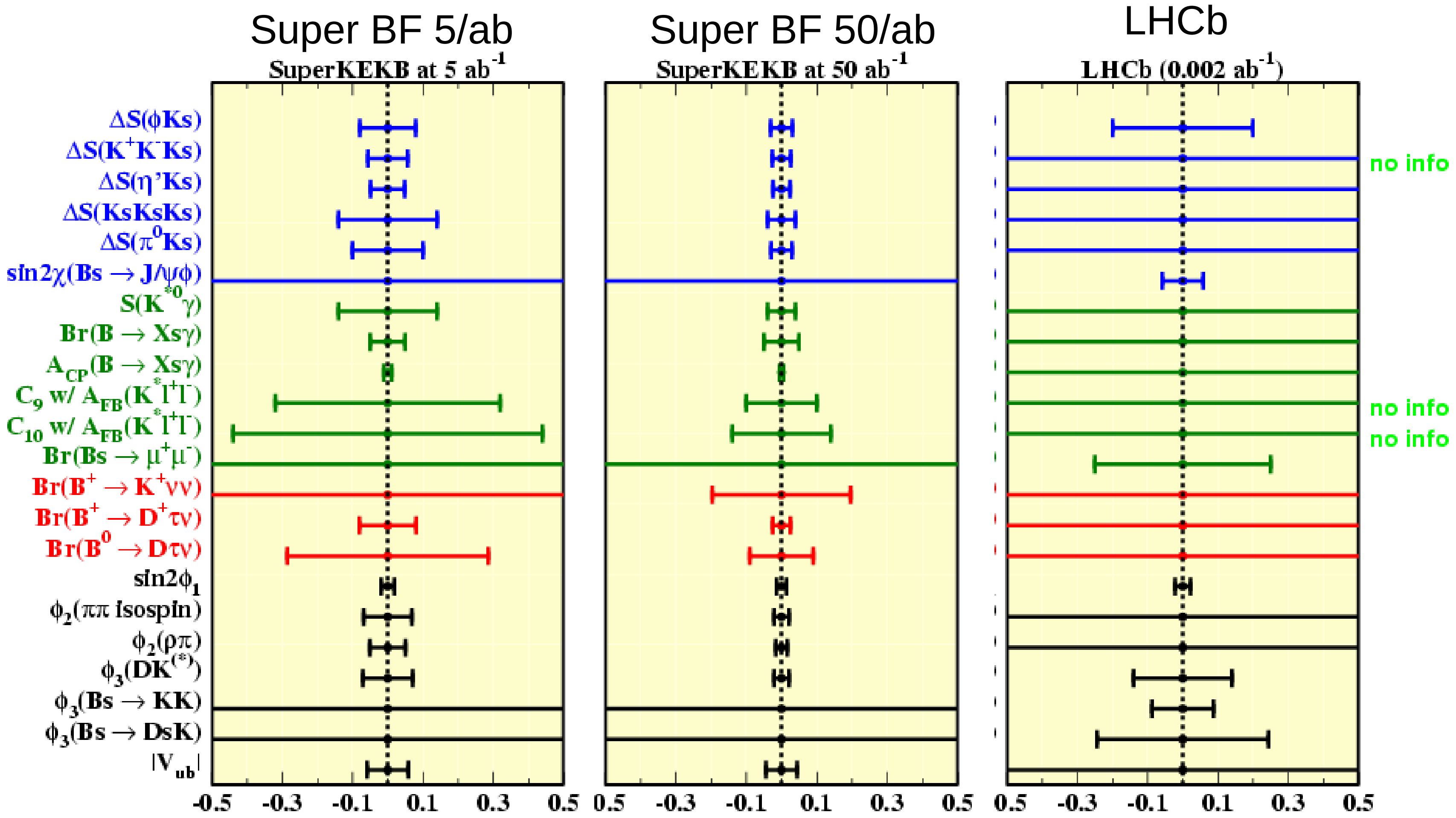
$$H = \frac{4G_F}{\sqrt{2}}\{C_7'(\bar{s}_R\sigma^{\mu\nu}b_L)F_{\mu\nu} + C_7(\bar{s}_L\sigma^{\mu\nu}b_R)F_{\mu\nu} + h.c\}$$

Acp~O(ms/mb) in SM

Branching ratio and lepton FB asymmetry in b -> s ll.
b-> s $\nu\nu$, B->$\tau\tau$, B->ll,
B->D $\tau\nu$ (Charged Higgs exchange)

Summary of physics reach

Super KEKB LoI



Complementarity between Super B Factory and hadron B programs

SUSY and Flavor Physics

- SUSY modes introduce SUSY partners.
- Squark mass matrixes are new sources of flavor mixing and CP violation.
- Squark masses depend on SUSY breaking terms as well as the Yukawa coupling constants.

quark (q)
lepton (l)
gluon (g)
W,Z,γ,H

squark $(\tilde{q})$
slepton $(\tilde{l})$
gluino $(\tilde{g})$
neutralino, chargino $(\tilde{\chi})$

Quark mass
$$(m_q)_{ij} = Y_{ij} v$$

Squark mass
$$(m^2_{\tilde{q}})_{ij} = (Y^\dagger Y)_{ij} v^2 + m^2_{ij}$$

SUSY breaking

- Squark mass matrixes carry information on the SUSY breaking mechanism and interactions at the GUT scale.

Origin of SUSY breaking
(mSUGRA, AMSB, GMSB, Flavor symmetry, etc.)

Renormalization
(SUSY GUT, neutrino Yukawa couplings etc.)

SUSY breaking terms at the Mw scale
(squark, slepton, chargino, neutralino, gluino masses)

Diagonal : LHC/LC
Off-diagonal: Future Flavor exp.

$$(m_{\tilde{q}}^2)_{ij} = \begin{pmatrix} m_{11}^2 & m_{12}^2 & m_{13}^2 \\ m_{21}^2 & m_{22}^2 & m_{23}^2 \\ m_{31}^2 & m_{32}^2 & m_{33}^2 \end{pmatrix}$$

Top quark: Tevatron
KM phase: B factories

Distinguishing different SUSY models

T.Goto, Y.Okada, Y.Shimizu, T.Shindou, and M.Tanaka

- In order to illustrate the potential of B physics in exploring flavor structure of SUSY breaking, we calculate various observables in four cases of SUSY models.

Models

1. Minimal supergravity model
2. SU(5) SUSY GUT with right-handed neutrino
   2-1. degenerate RHN case
   2-2. non-degenerate RHN case
3. MSSM with U(2) flavor symmetry

Observables

- Bd-Bd mixing, Bs-Bs mixing.
- CP violation in K-K mixing (ε).
- Time-dependent CP violation in B ->J/ψKs, B->ϕKs, B->K*γ .
- Direct CP violation in b->s γ.

Three SUSY Models

Origin of the squark mixing

$$(m^2_{\tilde{q}})_{ij} = (Y^\dagger Y)_{ij} v^2 + m^2_{ij}$$

1. Minimal supergravity model. Only the CKM matrix

Minimal Flavor Violation

Neutrino Flavor Mixing

2. SU(5) SUSY GUT with right-handed neutrino.
   The CKM matrix and the neutrino Yukawa coupling constants
   2-1. degenerate RHN case (μ -> e γ large)
   2-2. non-degenerate case (μ -> e γ suppressed)

$$m^2_{ij} \sim c(y^\dagger_\nu y_\nu)_{ij}$$

3. MSSM with U(2) flavor symmetry.
   Both Yukawa coupling constants and SUSY breaking terms
   have the (12)-3 structure.

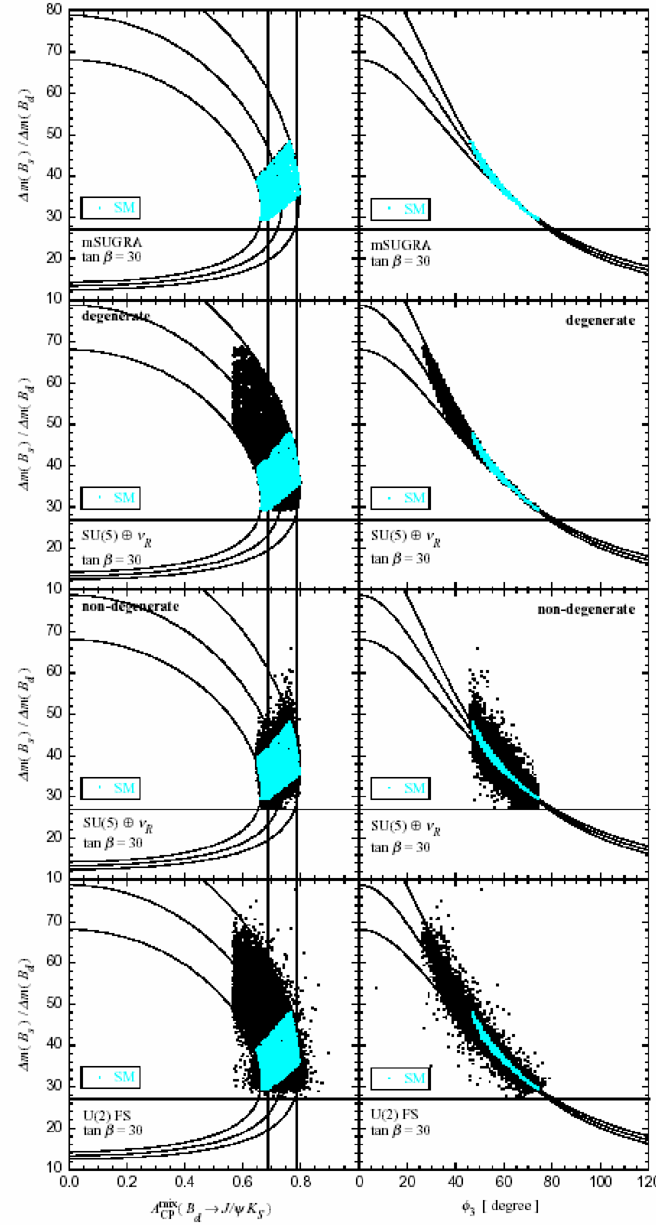
$$(m^2_{\tilde{q}})_{ij} \simeq \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1+O(\epsilon^2) & O(\epsilon) \\ 0 & O(\epsilon) & O(1) \end{pmatrix}$$

Approximate Flavor Symmetry

Unitarity triangle

- Small deviation in mSUGRA.
- Bd unitarity triangle is closed, but ε_K has a large SUSY contribution in SU(5) GUT for the degenerate M_R case.
- Bs mixing receives SUSY effects for the non-degenerate case.
- Various SUSY contributions for the U(2)flavor symmetry model.

Δm(Bs)/Δm(Bd)



mSUGRA

SU(5) GUT Degenerate

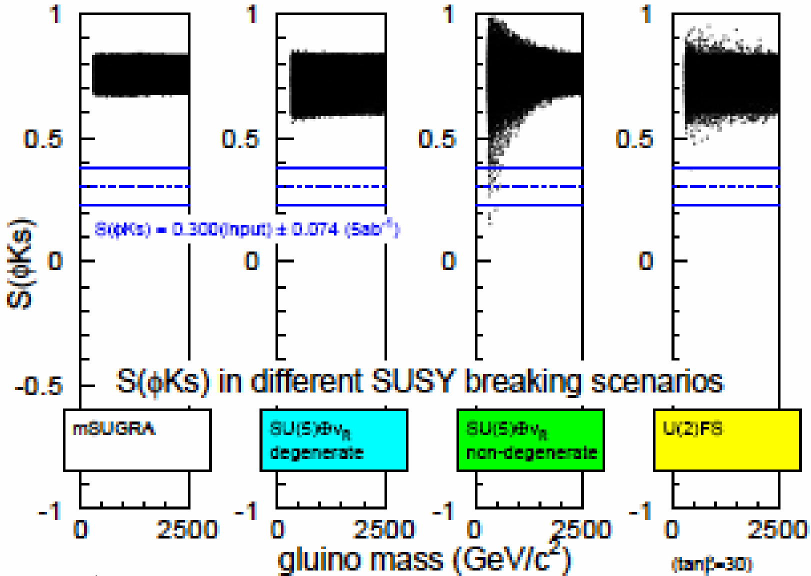
SU(5) GUT Non-degenerate

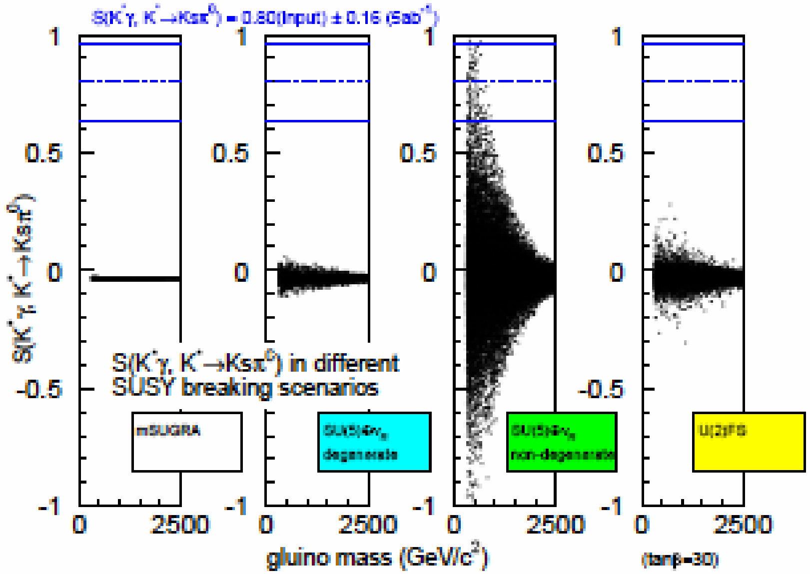
U(2) FS

A(B->J/ψKs)

φ3

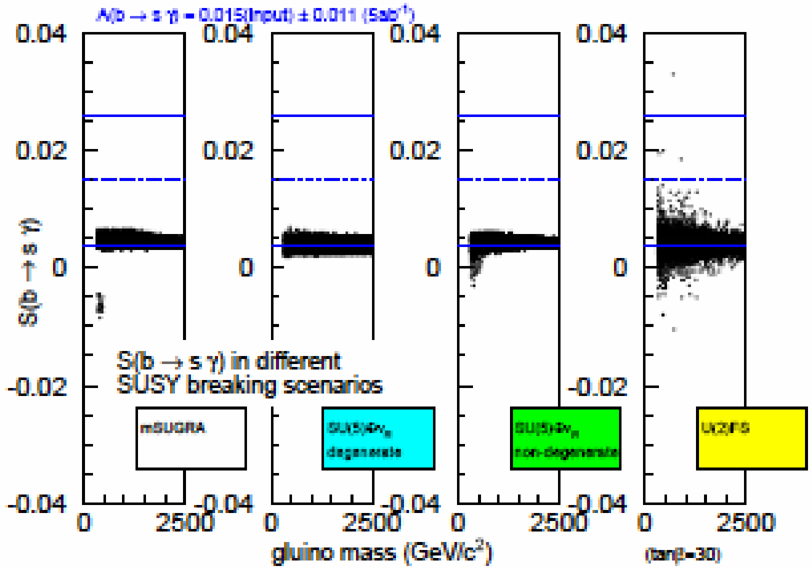
CP asymmetries in B –>ϕ Ks and b–> sγ





CP asymmetry in B –>ϕ Ks

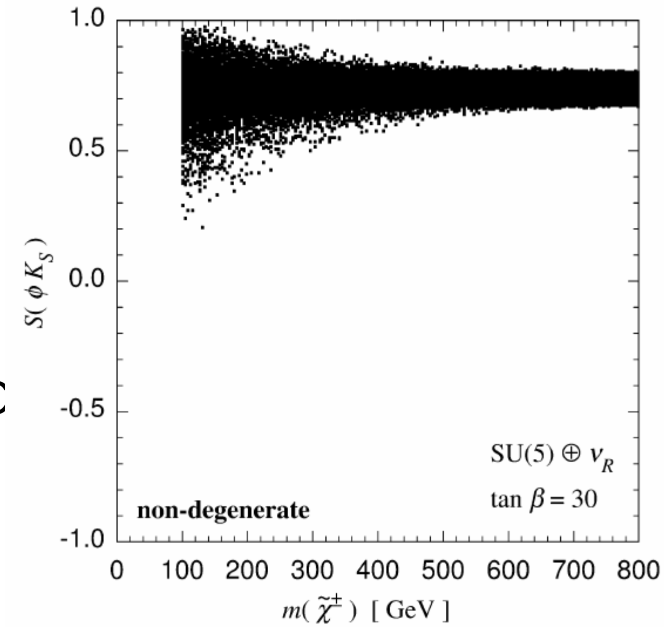
CP asymmetry in B –> K*γ



Direct asymmetry in b –> s γ

In the SU(5) +RHN with non-degenerate Majorana masses, if S(ϕKs)<0.5, then

S(ϕKs) vs chargino mass



Collider physics

Gluino mass < 800GeV
Stop mass < 800 GeV
} LHC

Lighter chargino mass <300 GeV
2nd neutralino mass <300 GeV
} LC

LFV

$$B(\mu \to e\gamma) > 10^{-14}$$ ← MEG (PSI) , MECO (BNL,μ-e conv. exp)

$$B(\tau \to \mu\gamma) > 10^{-9}$$ ← Super B factory

EDM

$$\text{neutron EDM} > 10^{-26}$$
$$\text{Hg EDM} > 10^{-29}$$
← One order of magnitude below the current bounds

Pattern of deviations from the SM prediction

	B_d unitarity			$A_{CP}^{\rm mix}$	$A_{CP}^{\rm mix}$	$A_{CP}^{\rm dir}$	$A_{CP}^{\rm mix}$
	closure	$+\epsilon_K$	$+\Delta m(B_s)$	$B \to \phi K_S$	$B \to K^* \gamma$	$B \to X_s \gamma$	$B_s \to J/\psi \phi$
mSUGRA	closed	-	-	-	-	-	-
SU(5) SUSY GUT (degenerate RHN)	closed	$\surd$	-	-	-	-	-
SU(5) SUSY GUT (non-deg. RHN)	closed	-	$\surd$	$\surd$	$\surd$	-	$\surd$
MSSM with U(2)	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$

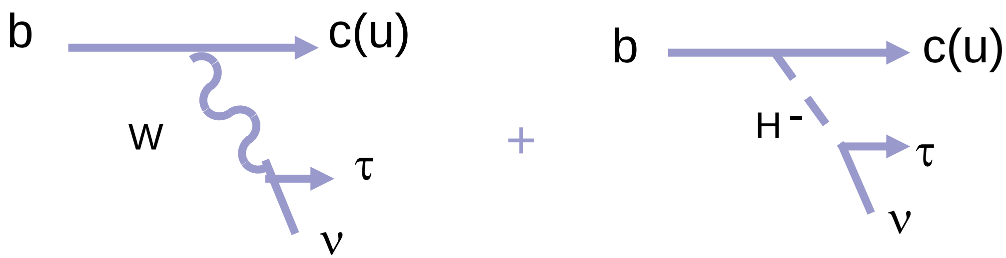
mSUGRA: small deviation
SUSY SU(5) with degenerate RHN: signals in 1-2 mixing
SUSY SU(5) with non-degenerate RHN: signals in 2-3 mixing
MSSM with U(2) FS: various new physics signals

SUSY with a minimal flavor violation (MFV)

- Even in the case where the squark flavor mixing is similar to the quark flavor mixing (MFV), a large deviation from the SM is possible for a large value of two vacuum expectation values (tan β).
- Effects can be significant for the charged Higgs boson exchange in B –> D $\tau\nu$ and B –> $\tau\nu$.
- Bs –> μ μ is enhanced by the loop-induced flavor changing neutral Higgs coupling.

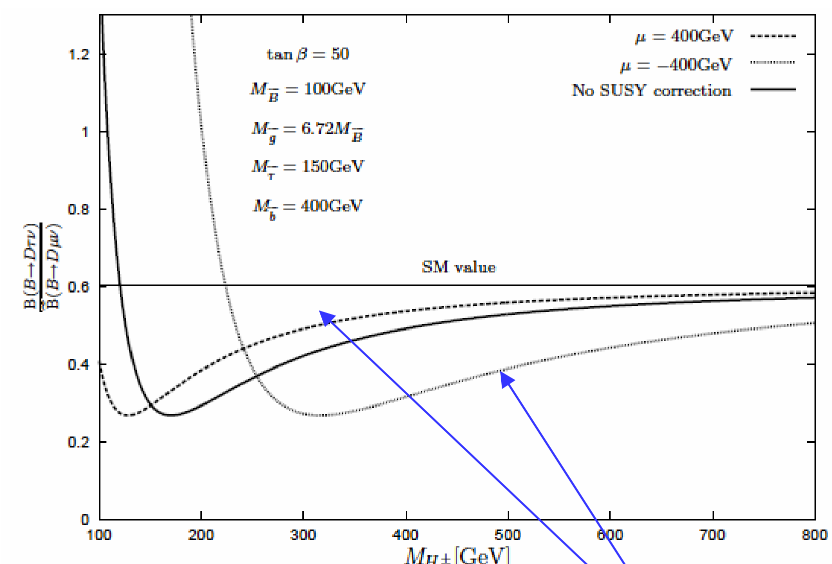
Tauonic B decay, B->D τν, B->τν

Charged Higgs boson exchange.



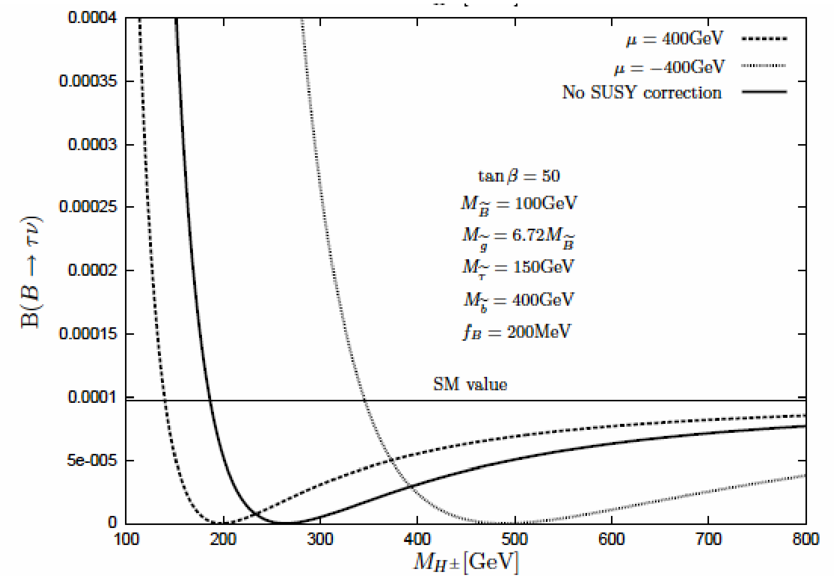
tan β=50

B->D τν



Charged Higgs mass

B->τν



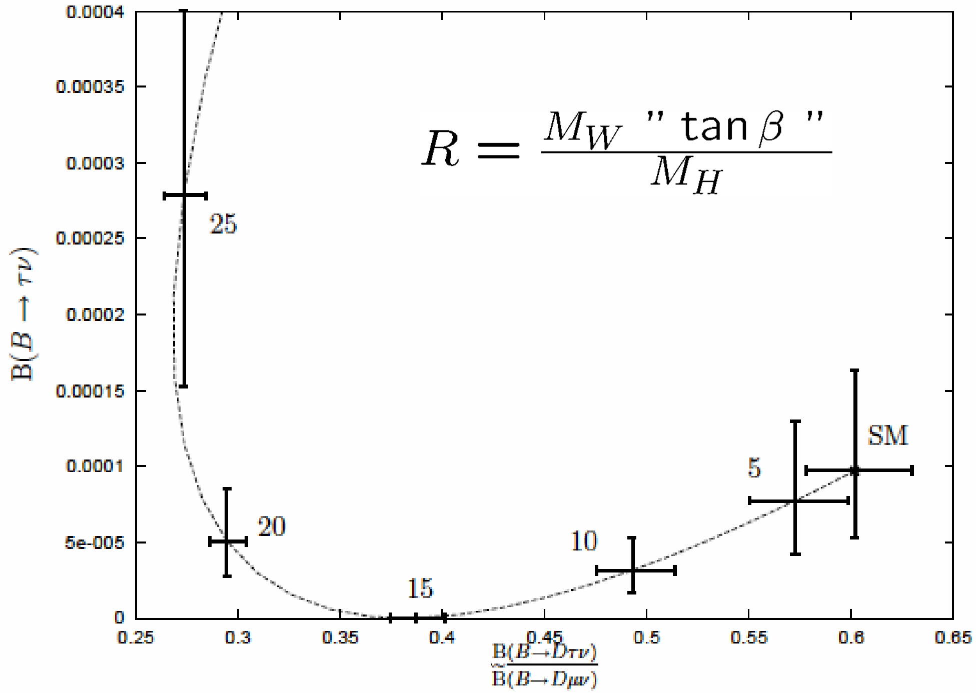
Charged Higgs mass

SUSY loop corrections to the Higgs vertex

H.Itoh, S.Komine, Y.Okada

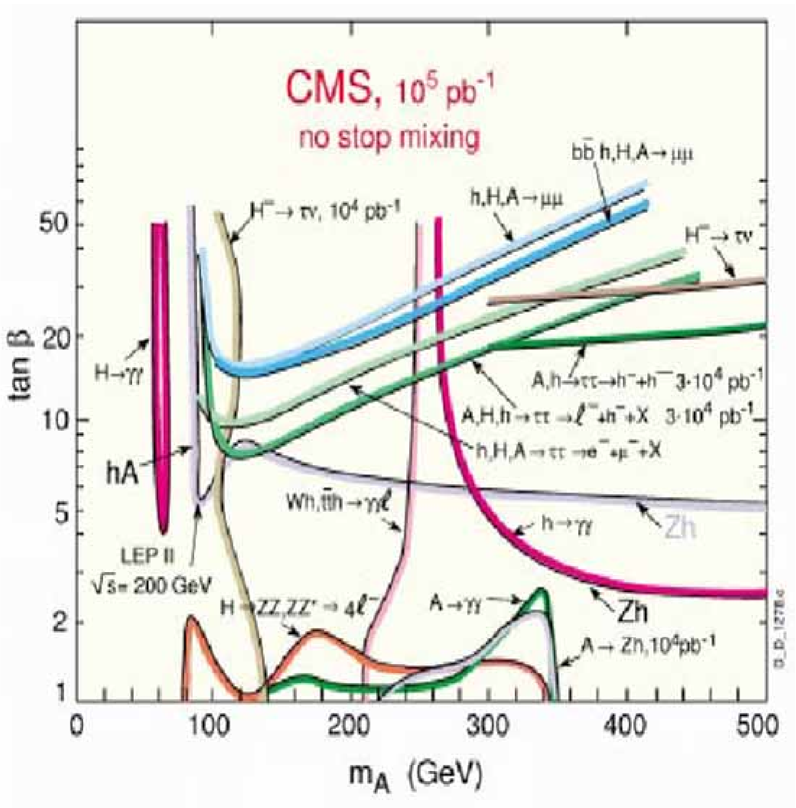
Correlation between B->D $\tau\nu$, B->$\tau\nu$

LHC heavy Higgs boson search



$$R = \frac{M_W \text{ '' } \tan\beta \text{ ''}}{M_H}$$

$$\frac{\mathrm{B}(B\to D\tau\nu)}{\mathrm{B}(B\to D\mu\nu)}$$



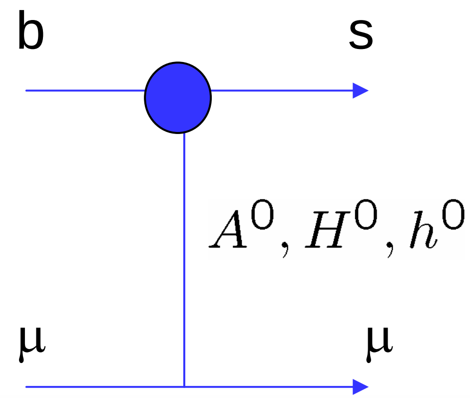
Super KEKB sensitivity from B->D$\tau\nu$

$$M_H > M_W \tan\beta/11 \text{ @5/fb (90\%CL limit)}$$

The covered parameter space
Is similar to LHC direct Higgs search

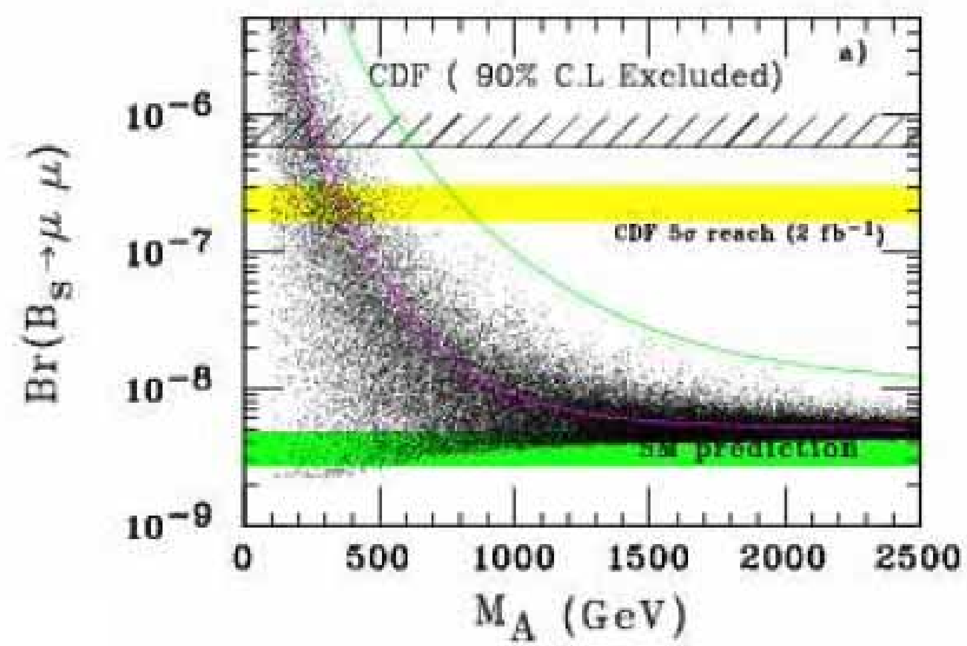
B(Bs–>μμ)

Loop-induced neutral Higgs exchange effects



- SUSY loop corrections can enhance B(Bs->μμ) by a few orders of magnitude from the SM prediction for large values of tan β.

  This is within the reach of Tevatron exp.



A.Dedes, B.T.Huffman

$$B(B_s \to \mu\mu) \sim 5\times 10^{-7}\left(\frac{\tan\beta}{50}\right)^6\left(\frac{300GeV}{M_A}\right)^4$$

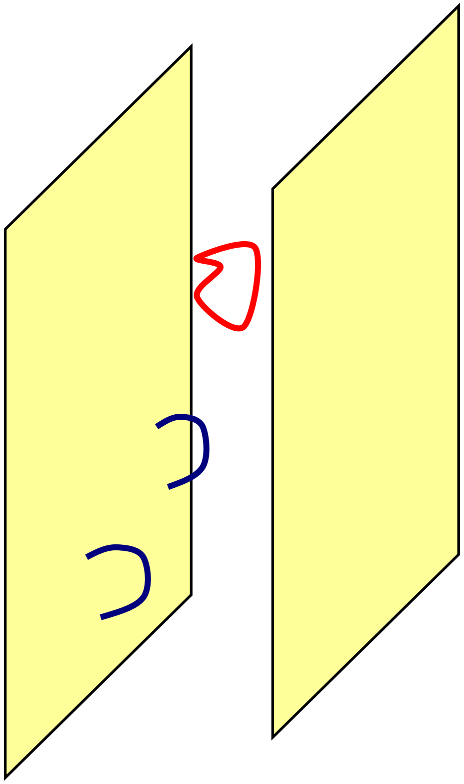
Large extra dim and B physics

- Models with large extra dimensions were proposed as an alternative scenario for a solution to the hierarchy problem.
- Various types of models:

  Flat extra dim vs. Curved extra dim

  What particles can propagate in the bulk.
- Geometrical construction of the fermion mass hierarchy

  => non-universality of KK graviton/gauge boson couplings



KK graviton exchange

KK graviton exchange can induce tree-level FCNC coupling.

$$O_{grav} = \frac{X}{M^4} T_{\mu\nu} T^{\mu\nu}$$

Differential branching ratio of b->sll processes.

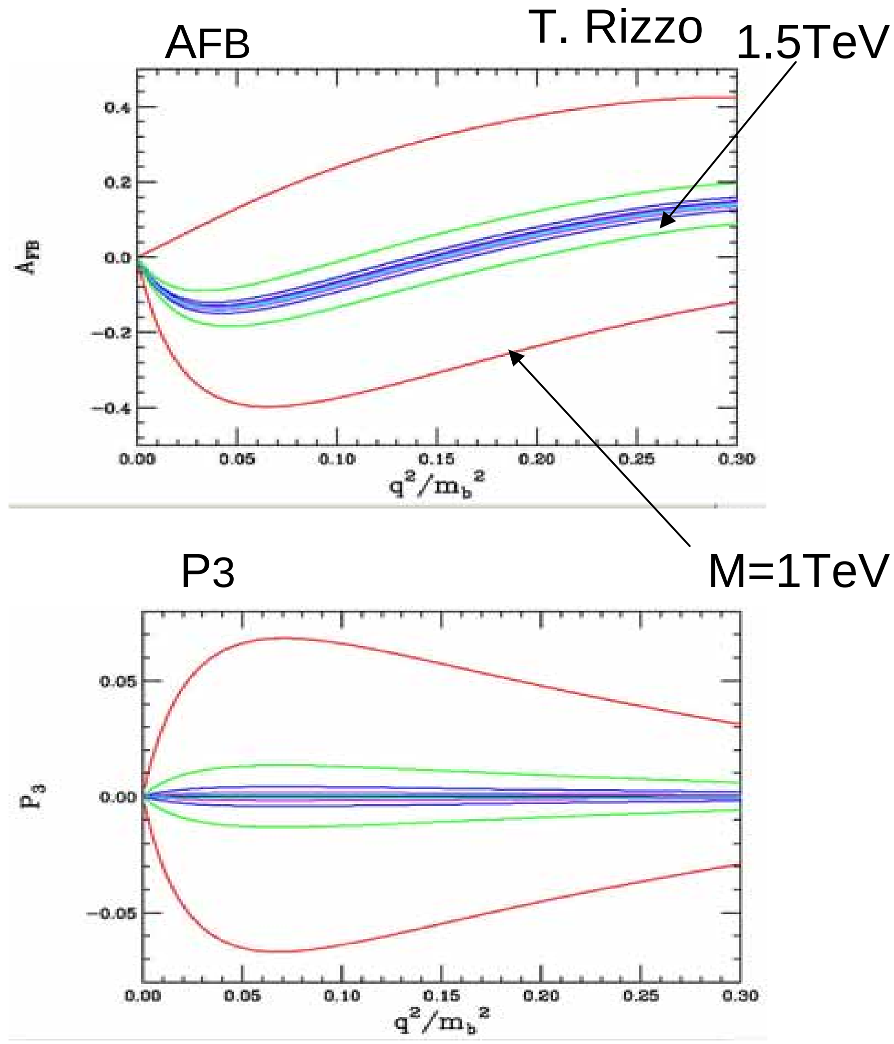
P3 : 3rd Legendre polynomial moment

=> pick up (cosθ)^3 terms due to spin2 graviton exchange.

(In both flat and curved extra dim)

T.Rizzo

b->sll differential Br



(Flat large extra dim case)

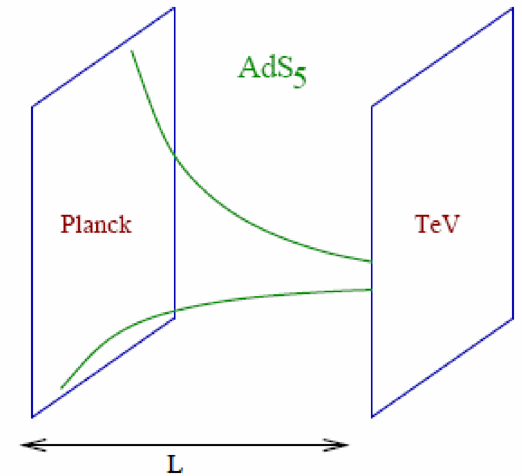
KK gluon, KK Z-boson exchange in warped extra dim.

In the warped extra dimension with bulk fermion/gauge boson propagation in order for the fermion mass hierarchy, we put

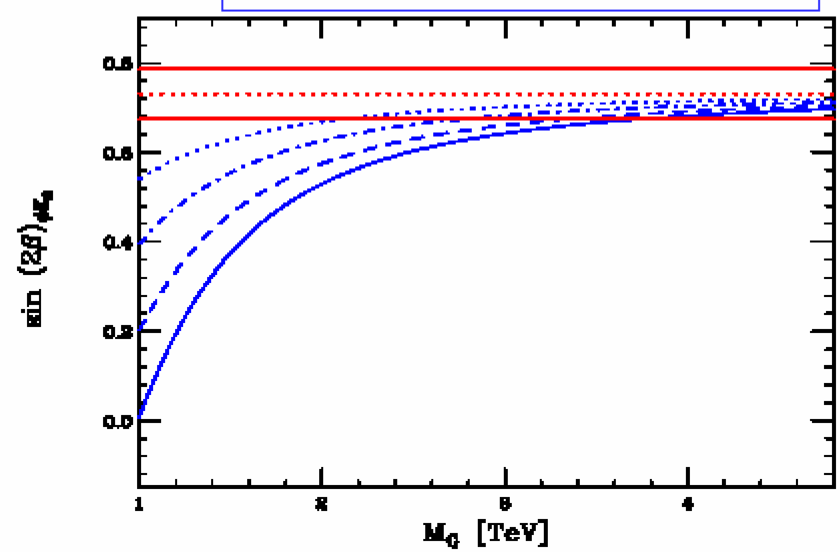
Light fermion -> localized toward Planck brane
Top and left-handed bottom -> localized toward the TeV brane.

$\Rightarrow$Generate tree level FCNC in KK gluon and Z boson exchange.

Various FCNC four fermion interactions
(S(ϕKs), b->sll, Bs-mixing, etc.)
A. Agashe,et.al; G.Burdman



S(ϕKs) vs KK gluon mass



1st KK gluon mass

G.Burdman

Summary of new physics signals

Model	B_d Unitarity	Time-dep. CPV	Rare B decay	Other signals
mSUGRA(moderate $\tan\beta$)	-	-	-	-
mSUGRA(large $\tan\beta$)	B_d mixing	-	$B \to (D)\tau\nu$ $b \to s\ell^+\ell^-$	$B_s \to \mu\mu$ B_s mixing
SUSY GUT with ν_R	-	$B \to \phi K_S$ $B \to K^*\gamma$	-	B_s mixing τ LFV, n EDM
Effective SUSY	B_d mixing	$B \to \phi K_S$	$A_{CP}^{b\to s\gamma}$, $b \to s\ell^+\ell^-$	B_s mixing
KK graviton exchange	-	-	$b \to s\ell^+\ell^-$	-
Split fermions in large extra dimensions	B_d mixing	-	$b \to s\ell^+\ell^-$	$K^0\overline{K}^0$ mixing $D^0\overline{D}^0$ mixing
Bulk fermions in warped extra dimensions	B_d mixing	$B \to \phi K_S$	$b \to s\ell^+\ell^-$	B_s mixing $D^0\overline{D}^0$ mixing
Universal extra dimensioins	-	-	$b \to s\ell^+\ell^-$ $b \to s\gamma$	$K \to \pi\nu\overline{\nu}$

In "The Discovery Potential of a Super B Factory",
The Proceedings of the 2003 SLAC Workshops

Summary

- Flavor physics tell us important aspects of new physics models.

  SUSY -> interactions at high energy scale.

  Large Extra Dim -> origin of fermion mass/flavor structure.
- There are a variety of ways to look for new physics effects in B decays.
- In order to distinguish different models, we need to know the pattern of deviations from SM predictions.
- Mutual impacts among B physics, K/D physics, LHC/LC, LFV, EDM, etc. are important.