1. INTRODUCTION

It is well-known that flavor changing neutral current (FCNC) interactions give an ideal place to search for new physics. Any positive observation of FCNC couplings deviated from that in SM would unambiguously signal the presence of new physics. Searching for FCNC is clearly one of important goals of the next generation of high energy colliders.

In this talk I shall concentrate on B leptonic rare decays. Experimental bounds are [1]:

\[ B_r(B_d \to \mu^+ \mu^-) < 6.8 \times 10^{-7} \quad (CL = 90\%) \]
\[ B_r(B_s \to \mu^+ \mu^-) < 2.6 \times 10^{-6} \quad (CL = 90\%) \]

In SM
\[ B_s(B_d \to \mu^+ \mu^-) = 1.9 \times 10^{-10} \]
\[ B_s(B_s \to \mu^+ \mu^-) = (3.7 \pm 1.2) \times 10^{-9}. \]

So there is a room for new physics.

\[ B_s \to \mu^+ \mu^- \] may be observable at Tevatron Run II soon [2]. If the decay was observed with \( Br = 2 \times 10^{-8} \), there would be new physics. Then, what is new physics?

2. SOME MODELS BEYOND SM

Among candidates of new physics, models beyond SM, MSSM and 2HDMs are the most promised. In 2HDM or SUSY the couplings of neutral Higgs bosons (NHBs) to down-type quarks or leptons are proportional to \( \frac{m_l}{m_W} \tan \beta \) which leads to significant effects on observables if \( \tan \beta \) is large. The models beyond SM we are interested in are as follows.

A. General Model II 2HDM

In a general model II 2HDM the free parameters are \( \tan \beta \), masses of Higgs bosons, and mixing angle of NHBs \( \alpha \).

B. Constrained MSSM

The scenarios we considered and free parameters in each scenario in the constrained MSSM (CMSSM) are listed in Table 1. In addition, we shall consider the CMSSM with nonuniversal gaugino masses [3] when discussing CP violation in the decays. Compared with mSUGRA with CP violating phases (the phase of the Higgsino mass parameter \( \mu \) and the phase of \( A \)), in the CMSSM with nonuniversal gaugino masses there are two more real parameters (say, \( |M_1| \) and \( |M_3| \), where \( M_1 \) and \( M_3 \) are gaugino masses corresponding to \( U(1) \) and \( SU(3) \) respectively) and two more independent phases arising from complex gaugino masses, which make the cancellations among various SUSY contributions to EDMs easier than in mSUGRA with CP violating

| models          | free parameters                  |
|-----------------|----------------------------------|
| mSUGRA          | \( \tan \beta, m_0, M_{1/2}, A \) |
| noscale SUGRA   | \( \tan \beta, M_{1/2}, \text{sign of } \mu \) |
| (m_0 = A = 0)   |                                  |
| dilaton scenario| \( \tan \beta, M_{1/2}, \text{sign of } \mu \) |
| \( m_0 = \frac{M_{1/2}}{\sqrt{3}} \) |                                  |
| \( A = -M_{1/2} \) |                                 |

Table 1
Scenarios we considered and free parameters in CMSSM
phases and relatively large values of the phase of \( \mu \) are allowed \[1\].

### 3. EFFECTIVE HAMILTONIAN

The effective Hamiltonian describing \( B_s \to l^+l^- \) in 2HDM and MSSM is \[\tilde{\mathcal{H}}\]

\[
H_{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[ \sum_{i=1}^{10} C_i(\mu) O_i(\mu) \right] + \sum_{i=1}^{10} C_Q_i(\mu) Q_i(\mu),
\]

where operators \( O_i \) can be found in ref.\[3\], and \( Q_i \)'s come from exchanging NHBs and have been given in ref.\[3\]. Wilson coefficients in 2HDM and CMSSM have been calculated and can be found in refs.\[2,3,6,10,11\]. We show the leading terms of relevant Wilson coefficients in large \( \tan \beta \) case in the following.

#### A. In a model II 2HDM

\( C_{10}(m_W) \) in the 2HDM is the same as that in SM for large \( \tan \beta \) scenario \[14\]. And \( C_Q_i \)'s are \[11\]

\[
C_{Q_1}(m_W) = f_{ac} y_t \left[ \frac{\ln y_t}{1 - y_t} - \frac{\sin^2(2\alpha)}{4} \frac{m_{H^0}^2 - m_{\phi}^2}{m_{H^0}^2 m_{\phi}^2} f_1(y_t) \right],
\]

\[
C_{Q_2}(m_W) = -f_{ac} y_t \ln y_t \frac{1}{1 - y_t}
\]

where

\[
f_{ac} = \frac{m_{\phi} m_t \tan^2 \beta}{4 \sin^2 \theta_W m_W^2}, \quad x_t = \frac{m_t^2}{m_W^2}, \quad y_t = \frac{m_t^2}{m_{H^0}^2},
\]

\[
f_1(y) = \frac{1 - y + y \ln y}{(y - 1)^2}.
\]

The difference between eq.(\[3\]) and the result in ref.\[11\] is that the second term in eq.(\[3\]) is absent in the paper.

#### B. In CMSSM

\[
C_{10}(m_W) = \frac{m_t^2 \tan^2 \beta \sqrt{x_{\chi_i^+} x_{\chi_i^-} U_{ij}^* U_{jk}^2}}{m_W^2}
\]

\[
f_{\phi \phi}(x_{\chi_i^+}, x_{\chi_i^-}, x_{\chi_k}, x_{\phi_i} + \ldots)
\]

\[
C_{Q_i}(m_W) = -\tan^3 \beta \frac{m_b m_{\phi}}{4 \sin^2 \theta_w m_W \lambda_i} \sum_{k=1}^{2} U_{ik} T_{UL}^{km} K_{mb}
\]

\[
\{ -\sqrt{2} V_{i1}^* (T_{UL} K)_{ks} + V_{i2}^* (T_{UR} m_{\phi} K)_{ks} \}
\]

\[
r^{\text{ker}} \sqrt{x_{\chi_i^-} f_B^0} (x_{\chi_i^-}, x_{\phi_k}) + O(\tan^2 \beta), \quad (4)
\]

\[
C_{Q_2}(m_W) = \tan^3 \beta \frac{m_b m_{\phi}}{4 \sin^2 \theta_w m_W \lambda_i} \sum_{k=1}^{2} U_{ik} T_{UL}^{km} K_{mb}
\]

\[
\{ -\sqrt{2} V_{i1}^* (T_{UL} K)_{ks} + V_{i2}^* (T_{UR} m_{\phi} K)_{ks} \}
\]

\[
r^{\text{ker}} \sqrt{x_{\chi_i^-} f_B^0} (x_{\chi_i^-}, x_{\phi_k}) + O(\tan^2 \beta), \quad (5)
\]

where \( U \) and \( V \) are matrices which diagonalize the mass matrix of charginos, \( T_{UL} \) (i=L, R) is the matrix which diagonalizes the mass matrix of the scalar up-type quarks and \( K \) is the CKM matrix.

The \( \tan^3 \beta \) enhancement of \( C_{Q_i} \) (i=1,2) was first shown in refs.\[6,10\] and confirmed later in refs.\[10\]. The chargino-chargino box diagram gives a contribution proportional to \( \tan^2 \beta \) to \( C_{10} \). Numerically, \( C_{10} \) is enhanced in CMSSM at most by about 10% compared with SM.

### 4. NUMERICAL RESULTS OF Br

The contributions from NHBs always increase the branching ratios in the large \( \tan \beta \) case so that the branching ratios in the 2HDM and in SUSY models are larger than those in SM.

#### A. In a general model II 2HDM

1. Br of \( B_s \to \mu^+ \mu^- \) is about 10^{-8}, an order of magnitude larger than that in SM, if \( \tan \beta = 60 \) or so, \( \alpha \geq \pi/4 \) and the other parameters are in reasonable range.

#### B. The Br increases when the splitting of the masses of the two CP even neutral Higgs bosons increases except for the case of the mixing angle \( \alpha=0 \).

#### B. In CMSSM

1. the Br can saturate the experimental bound in some regions of the parameter space where \( C_{Q_i} \)'s (i=1,2) behave as \( \tan^3 \beta \). In the other regions where \( C_{Q_i} \)'s (i=1,2) behave as \( \tan^2 \beta \) the Br is
about the order $10^{-8}$.
2. If the Br $2 \times 10^{-8}$ is observed, then SUSY breaking mediation (SBM) mechanisms such as $m_0 = 0$ scenario (e.g., noscale SUGRA), gMSB, GMSB with small number of messenger fields or low messenger scale, the minimal AMSB are excluded, imposing the constraint from $B \to X_s \gamma$ and the direct search bounds on sparticles and Higgs.

5. CP VIOLATION

CP violation in the $b$-system has been established from measurements of time-dependent asymmetries in $B \to J/\Psi K$ decays. We shall show that to observe the CP asymmetry in the $B$ decays to a pair of muons or taus is a good way to search for new physics. Direct CP violation is absent and no $T$-odd projections can be defined. However, there is CP violation induced by $B^0 - \bar{B}^0$ mixing in the process $B^0 \to \bar{B}^0 \to f$ vs. $\bar{B}^0 \to B^0 \to \bar{f}$.

One can define the CP violating observable as

$$A_{CP} = \frac{D}{S},$$

$$D = \int_0^\infty dt \sum_{i=1,2} \Gamma (B^0_{phys}(t) \to f_i)$$

$$- \int_0^\infty dt \sum_{i=1,2} \Gamma (\bar{B}^0_{phys}(t) \to f_i),$$

$$S = \int_0^\infty dt \sum_{i=1,2} \Gamma (B^0_{phys}(t) \to f_i)$$

$$+ \int_0^\infty dt \sum_{i=1,2} \Gamma (\bar{B}^0_{phys}(t) \to f_i)$$

$$q/p = - \frac{M_{12}^2}{|M_{12}|} = - \frac{\lambda_i^*}{\lambda_i},$$

where $f_{1,2} = l_L^+ R^* l_L^R$, with $l_L(R)$ being the helicity eigenstate of eigenvalue $-1(+1)$, $f_i$ is the CP conjugate state of $f_i$.

In SM, one has

$$A_{CP} = - \frac{2Im(\xi)X_q}{(1 + |\xi|^2)(1 + X_q^2)}, \quad q = d, s,$$

where $X_q = \frac{\Delta m_q}{m_q}$ for $B^0_d$ and $B^0_s$,

$$\xi = \frac{C_{Q1} \sqrt{1 - 4m^2_f + (C_{Q2} + 2m_tC_{10})}}{C_{Q1} \sqrt{1 - 4m^2_f - (C_{Q2} + 2m_tC_{10})}}.$$ (9)

In eq. (8), $m_t = m_t/4m_0$. In SM $C_{10}$ is real, $C_{Q2} = 0$, and $C_{Q1}$ is negligibly small. Therefore, there is no CP violation in SM. If one includes the correction of order of $10^{-2}$ to $|\xi| = 1$, one will have CP violation of order of $10^{-3}$ which is unobservably small.

In MSSM we can still use eq. (8) in the approximation, eq. (9), which is a good approximation in MSSM if one limits himself to the regions with large tan $\beta$ (say, larger than 10 but smaller than 60), not too light charged Higgs boson (say, larger than 250 Gev), and heavy sparticles, and in the scenarios of the minimal flavor violation (MFV) without new CP violating phases there is no correction to eq. (8). In MFV models with new CP violating phases, e.g., in the CMSSM with nonuniversal gaugino masses which we consider in this section, a rough estimate gives that the correction to the SM value of $q/p$ is below 20% in the parameter space we used in calculations.

It should be pointed out that there is no hadronic uncertainty since the common uncertain decay constant cancels out in eq. (8).

In a 2HDM with CP violating phases and CMSSM with nonuniversal gaugino masses the CP asymmetries depend on the parameters of models and can be as large as 40% for $B^0_d$ and 3% for $B^0_s$, while the constraints from EDMs of electron and neutron are satisfied.

The correlations between $(g - 2)_\mu$ and CP asymmetries in $B^0_{d,s} \to l^+ l^-$ and $b \to s \gamma$ in SUSY models with nonuniversal gaugino masses have been calculated in ref. [21], imposing the constraints from the branching ratio of $B \to X_s \gamma$ (it leads to the correlation between $C_{7}^{eff}$ and $C_{9}$ in SUSY models) and EDMs of electron and neutron, and the results are

---with a good fit to the muon $g - 2$ constraint,
the CP asymmetry can be as large as 25% (15%) for $B^0_d \rightarrow \tau^+\tau^-$ ($B^0_d \rightarrow \mu^+\mu^-$) in CMSSM with nonuniversal gaugino masses and MFV scenarios of MSSM.

—If tau events identified with 6% tagging error, one can measure $A_{CP}$ to a 3σ level at Tevatron Run II with $\text{Br}(B_d \rightarrow \tau^+\tau^-)$ enhanced by a factor of about 30 compared to that of SM.

—A scenario in which new physics only increases the Br a little and the Br is still in the uncertain region of the SM prediction. The CP asymmetry for $B^0_q \rightarrow l^+l^-$ in the scenario can still reach 20% allowed by the muon g-2 constraint within 2σ deviations. So it is powerful to shed light on physics beyond SM while the CP asymmetry of $b \rightarrow s\gamma$ in this case can only reach 2% at most which is too small to draw a definite conclusion on new physics effects at B factories.

6. CONCLUSIONS

The following conclusions can be drawn from the above discussions.

If Br($B_s \rightarrow \mu^+\mu^-$) $2 \times 10^{-8}$ (or larger) is observed at Tevatron Run II, then there exits new physics. If new physics is a model II 2HDM or CMSSM, the new contributions must (mainly) come from NHBs ($C_{10}$ enhanced in CMSSM at most by about 10%) and tan $\beta$ must be large:

A. for a model II 2HDM, tan $\beta$ must be larger than about 60;

B. for constrained MSSM, tan $\beta$ must be larger than about 30.

And some SUSY breaking mediation mechanisms would be excluded.

In the near future when very high statistics can be reached measurements of the decays $B_s \rightarrow l^+l^-$ ($l=\mu, \tau$) could provide a large potential to find or exclude the large tan $\beta$ parts of the parameter space in 2HDM and/or SUSY.

An observation of CP asymmetry in the decays $B^0_q \rightarrow l^+l^-$ ($q = d, s, l = \mu, \tau$) would unambiguously signal the existence of new physics.

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