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The like-sign dimuon charge asymmetry in SUSY models

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ABSTRACT

We study the new physics (NP) implications of the recently reported 3.2σ Standard Model (SM) deviation in the like-sign dimuon asymmetry at the Tevatron. Assuming that new physics only enters the B_s mixing amplitude we explore the implications for generic new physics, general supersymmetric (SUSY) models and also SUSY SU(5). In the case of SUSY SU(5) we exploit the GUT scale relationship between slepton and squark soft masses to predict rates for lepton flavour violation (LFV). The predicted rates for $\tau \to \mu\gamma$ are found to be detectable at future Super-B factories.

1. Introduction

The Standard Model (SM), with the phase of the Cabibbo–Kobayashi–Maskawa (CKM) matrix as the sole source of CP violation, predicts a very small violation of CP in B meson mixing. While observations of B_d mixing conform to this paradigm, in the B_s system there have begun to emerge hints of physics beyond the SM. The first measurements of B_s–$\bar{B}_s$ mixing and its associated CP phase have been observed by the Tevatron's DØ [1–3] and CDF [4,5] Collaborations. Although the mass difference ΔM_s shows little deviation from what is expected in the SM, the CP phase ϕ_s observed in $B_s \to \psi\phi$ decays is found to deviate from the SM by almost 3σ.

More recently, the DØ Collaboration reported a 3.2σ SM deviation in the like-sign dimuon charge asymmetry [6],

$$a_{sl}^{b} = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} = -(9.57 \pm 2.51 \pm 1.46) \times 10^{-3} \tag{1}$$

where $N_b^{\pm\pm}$ is the number of semileptonic events $b\bar{b} \to \mu^{\pm}\mu^{\pm}X$, and the SM prediction is given as $a_{sl}^{b,\mathrm{SM}} = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$ [7]. If we assume that there is negligible CP violation in the tree-level decay amplitude then this measurement can be interpreted as further evidence for large CP violation in B_s mixing.

An earlier result by the CDF Collaboration found [8], $a_{sl}^{b} = (8.0 \pm 9.0 \pm 6.8) \times 10^{-3}$, which has larger uncertainty yet is still compatible with the DØ result. As the Tevatron produces both B_d and B_s mesons this measurement is a linear combination of the individual asymmetries,

$$a_{sl}^{b} = (0.506 \pm 0.043)a_{sl}^{d} + (0.494 \pm 0.043)a_{sl}^{s}. \tag{2}$$

Using the average of the CDF and DØ results for a_{sl}^{b} and assuming that new physics doesn't enter B_d mixing we find,

$$a_{sl}^{s} = -(17.2 \pm 5.9) \times 10^{-3}. \tag{3}$$

The direct measurement by DØ [9], $a_{sl}^{s} = -(1.7 \pm 9.1) \times 10^{-3}$, has larger uncertainty yet still agrees with the value derived above. Taking the average of these we arrive at the combined result,

$$(a_{sl}^{s})_{\mathrm{combined}} = -(12.7 \pm 5.0) \times 10^{-3} \tag{4}$$

which we shall use in the analysis which follows.

The dimuon asymmetry has already been investigated in the context of generic new physics [10] and specific new physics models, for example models with flavour changing neutral Higgs [11], flavour changing Z' [12], or Axigluons [13] (see also [14]). In this work we examine the implications of the recent measurement of a dimuon asymmetry in SUSY models. We first investigate the implications of the recent measurement of a_{sl}^{b} in generic new physics before studying the dominant SUSY contributions in the mass insertion approximation (MIA). The preferred mass insertion parameter region is determined for two sample SUSY input points. In the context of SUSY SU(5) we then exploit the GUT relationship of squark and slepton mass insertions to make predictions for the rates of $\tau \to \mu\gamma$ in light of this latest measurement.

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2. Constraints on new physics from B_s mixing and a_{sl}^s

The $\Delta B = 2$ transition between B_s and $\bar{B}_s$ mesons is defined as

$$\langle B_s^0 | \mathcal{H}_{eff}^{\Delta B=2} | \bar{B}_s^0 \rangle = 2 M_{B_s} M_{12}^s \tag{5}$$

where M_{B_s} is the mass of the B_s meson. We can then define the B_s mass eigenstate difference as

$$\Delta M_s \equiv M_H^s - M_L^s = 2 |M_{12}^s| \tag{6}$$

and its associated CP phase,

$$\phi_s = \arg(-M_{12}^s / \Gamma_{12}^s). \tag{7}$$

In the Standard Model M_{12}^s is given by

$$M_{12}^{s,\mathrm{SM}} = \frac{G_F^2 M_W^2}{12\pi^2} M_{B_s} \hat{\eta}^B f_{B_s}^2 \hat{B}_{B_s} (V_{ts}^* V_{tb})^2 S_0(x_t) \tag{8}$$

where G_F is Fermi's constant, M_W the mass of the W boson, $\hat{\eta}^B = 0.551$ is a short-distance QCD correction. The bag parameter $\hat{B}_{B_s}$ and decay constant f_{B_s} are non-perturbative quantities and contain the majority of the theoretical uncertainty. V_{ts} and V_{tb} are elements of the CKM matrix, and $S_0(x_t \equiv \bar{m}_t^2 / M_W^2)$ is the usual Inami–Lim function.

The Standard Model predictions for the other parameters relevant to B_s mixing are [7]

$$\Delta\Gamma^{s,\mathrm{SM}} = (0.096 \pm 0.039)\ \mathrm{ps}^{-1}, \tag{9}$$

$$\phi_s^{\mathrm{SM}} = (4.2 \pm 1.4) \times 10^{-3}. \tag{10}$$

Generic NP contributions to B_s mixing may be parameterized as

$$\Delta M_s = \Delta M_s^{\mathrm{SM}} |1 + R_s|, \tag{11}$$

$$\phi_s = \phi_s^{\mathrm{SM}} + \phi_s^{\mathrm{NP}} = \phi_s^{\mathrm{SM}} + \arg(1 + r_s e^{i\sigma_s}) \tag{12}$$

where $R_s \equiv r_s e^{i\sigma_s} = M_{12}^{s,\mathrm{NP}} / M_{12}^{s,\mathrm{SM}}$ denotes the relative size of the NP contribution.

From the definition of Eq. (11) we have the constraint,

$$\rho_s \equiv \frac{\Delta M_s}{\Delta M_s^{\mathrm{SM}}} = \sqrt{1 + 2 r_s \cos\sigma_s + r_s^2} \tag{13}$$

for r_s and σ_s. The UTfit analysis [15] gives ρ_s at the 95% C.L. to be,

$$\rho_s = [0.776, 1.162]. \tag{14}$$

From Eq. (12) the phase associated with NP can also be written in terms of r_s and σ_s,

$$\sin\phi_s^{\mathrm{NP}} = \frac{r_s \sin\sigma_s}{\sqrt{1 + 2 r_s \cos\sigma_s + r_s^2}}, \tag{15a}$$

$$\cos\phi_s^{\mathrm{NP}} = \frac{1 + r_s \cos\sigma_s}{\sqrt{1 + 2 r_s \cos\sigma_s + r_s^2}}. \tag{15b}$$

Here [15] gives the 95% C.L. constraint,

$$\phi_s^{\mathrm{NP}} = [-162, -102]^\circ \cup [-76, -12]^\circ \tag{16}$$

with a two-fold ambiguity.

In order to consistently apply the above constraints all input parameters are chosen to match those used in the analysis of the UTfit group [15,17] with the non-perturbative parameters,

$$f_{B_s} \sqrt{\hat{B}_{B_s}} = 270 \pm 30\ \mathrm{MeV}, \tag{17}$$

$$f_{B_s} = 245 \pm 25\ \mathrm{MeV}. \tag{18}$$

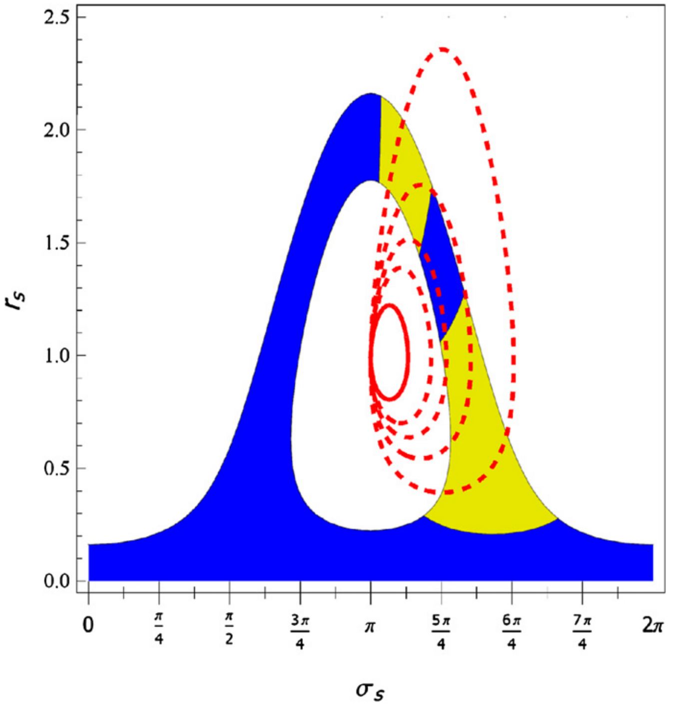

Fig. 1. The r_s–σ_s generic new physics parameter space allowed by the mass difference ΔM_s (blue/black) and ϕ_s (yellow/light grey) at 95% C.L.. The solid red curve corresponds the central value in Eq. (4), $a_{sl}^s = -12.7 \times 10^{-3}$. The dashed red curves, from inner to outer curve, correspond to $a_{sl}^s = -(7.7, 6.0, 4.4, 2.7) \times 10^{-3}$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this Letter.)

Finally, the asymmetry a_{sl}^s is defined as

$$a_{sl}^s = \frac{2 w_s z_s \sin\phi_s}{w_s^2 + z_s^2} \simeq \frac{|\Gamma_{12}^s|}{|M_{12}^{s,\mathrm{SM}}|} \frac{\sin\phi_s}{|1 + r_s e^{i\sigma_s}|} \tag{19}$$

where $w_s = 2|M_{12}^s|/\Gamma_s$ and $z_s = |\Gamma_{12}^s|/\Gamma_s$. We shall assume that NP enters into the mixing amplitude only and take $\Gamma_{12}^s \equiv \Gamma_{12}^{s,\mathrm{SM}}$. In our numerical analysis we use the combined value of a_{sl}^s in Eq. (4) to constrain the NP parameter space.

Fig. 1 shows the r_s–σ_s NP parameter space allowed by the constraints of ΔM_s and ϕ_s^{NP}. The shaded blue/black region depicts the parameter space determined by the 95% C.L. bound from the ΔM_s measurement, while the two yellow/light grey regions represent the combined 95% C.L. bounds of both ΔM_s and ϕ_s. Also displayed are red contour lines for the dimuon asymmetry a_{sl}^s. The solid red curve corresponds to the central value given in Eq. (4) while the 1σ and 2σ regions are shown by the inner most and outer most dashed red curves respectively. At the 2σ level we can see that although the two-fold ambiguity in the CP phase ϕ_s isn't resolved by the measurement of a_{sl}^s, the parameter space is further restricted. If the CP violation observed in the dimuon asymmetry indeed corresponds to NP in B_s mixing the tension between a_{sl}^s and ϕ_s implies that the central value of a_{sl}^s should increase somewhat in the future.

Recently DØ and CDF released new results based on 6.1 fb^{-1} [18] and 5.2 fb^{-1} [19] of integrated luminosity. These results are still preliminary and have not yet been combined together. As a result we shall not use these results in the present analysis.

In the follow section we study the implications of the dimuon asymmetry for the allowed mass insertion parameter space of SUSY models and also for the predictions of large $\tau \to \mu\gamma$ rates in SUSY SU(5).

3. The dimuon charge asymmetry in supersymmetric models

The dominant SUSY contribution to B_s mixing comes from the gluino contribution which may be written as [20],

$$R_s^{\tilde{g}} \equiv \frac{M_{12}^{s,\tilde{g}}}{M_{12}^{s,\mathrm{SM}}} = a_1^s(m_{\tilde{g}}, x)\big[\big(\delta_{RR}^d\big)_{23}^2 + \big(\delta_{LL}^d\big)_{23}^2\big] + a_4^s(m_{\tilde{g}}, x)\big(\delta_{LL}^d\big)_{23}\big(\delta_{RR}^d\big)_{23} + \cdots \tag{20}$$

where x denotes the ratio of the squared gluino and down-squark masses, $x = m_{\tilde{g}}^2/m_{\tilde{d}}^2$. The functions $a_{1,4}^s$ can be found in [20,21]. Here we have ignored terms proportional to $\delta_{RL,LR}^d$ mass insertions as they are expected to be heavily suppressed due to constraints from $b \to s\gamma$.

In Fig. 2 we show the constraints on the mass insertion parameter space of $(\delta_{RR}^d)_{23}$ from the 95% C.L. bounds of the mass difference ΔM_s (blue/black), the CP phase ϕ_s (yellow/light grey) and the dimuon asymmetry a_{sl}^s (red curves). Again, the solid red curve corresponds to the central value of a_{sl}^s from Eq. (4), while the 1σ and 2σ bounds are shown by the inner most and outer most dashed red curves respectively. At the 2σ level the new value of a_{sl}^s agrees well with both of the regions allowed by the combined ΔM_s and ϕ_s bounds shown by the yellow/light grey shaded areas. This is similar to what we have found already in Fig. 1. At the 1σ level there is a slight tension between a_{sl}^s and the CP phase ϕ_s which indicates that we should either expect the central value of a_{sl}^s to increase somewhat in the future, or that new physics also enters into the width difference, as discussed in [23].

In SU(5) the quarks and leptons are placed into $\mathbf{10} = (Q, u^c, e^c)$ and $\bar{\mathbf{5}} = (L, d^c)$ representations. Due to the symmetry of this simple SUSY GUT there exists relations amongst the slepton and squark soft SUSY breaking masses,

$$m_{10}^2 = m_{\tilde{Q}}^2 = m_{\tilde{U}}^2 = m_{\tilde{E}}^2, \qquad m_5^2 = m_{\tilde{L}}^2 = m_{\tilde{D}}^2. \tag{21}$$

These relations hold for scales at and above the GUT scale. Interestingly this implies that left-handed slepton mixing and right-handed down squark mixing are related. This relation can still be felt very strongly at the Electroweak scale in the correlation of LFV rates and FCNCs.

Due to these GUT scale relations the $(\delta_{RR}^d)_{23}$ contributions to FCNCs and $(\delta_{LL}^l)_{23}$ contributions to LFV are clearly correlated. As a result we may explicitly write the rate of $\tau \to \mu\gamma$ in the form,

$$Br(\tau \to \mu\gamma) \simeq \frac{\alpha^3}{G_F^2}\frac{m_{\tilde{d}}^4}{M_S^8}\big|\big(\delta_{RR}^d\big)_{23}\big|^2 \tan^2\beta \tag{22}$$

where $m_{\tilde{d}}$ is the average down squark mass and M_S is the typical slepton mass.

We shall also consider the RGE effects of the CKM mixings in the left-handed down squark matrices. At the SUSY scale M_{SUSY} these effects can be approximated as

$$\big(\delta_{LL}^d\big)_{23} \approx -\frac{1}{8\pi^2} y_t^2 V_{ts}^* V_{tb} \frac{(3m_0^2 + A_0^2)}{m_{\tilde{d}}^2} \ln \frac{M_{GUT}}{M_{SUSY}}. \tag{23}$$

Here m_0 is the universal scalar mass, A_0 the universal A-term and M_{GUT} is the scale of SU(5) unification.

In Fig. 3 we explore the correlation between B_s mixing and the branching ratio for $\tau \to \mu\gamma$ in SUSY SU(5) where we have taken $\tan\beta = 10$.[1] The predicted rates for $\tau \to \mu\gamma$ can be scaled by $(\tan\beta/10)^2$ for different values of $\tan\beta$. In [21] it was found that the large CP phase ϕ_s restricts the mass insertion parameter space such that large rates for $\tau \to \mu\gamma$ are expected in the case of SUSY SU(5) as shown by the yellow/light grey points in Fig. 3. From the yellow/light grey points we find an approximate lower bound of

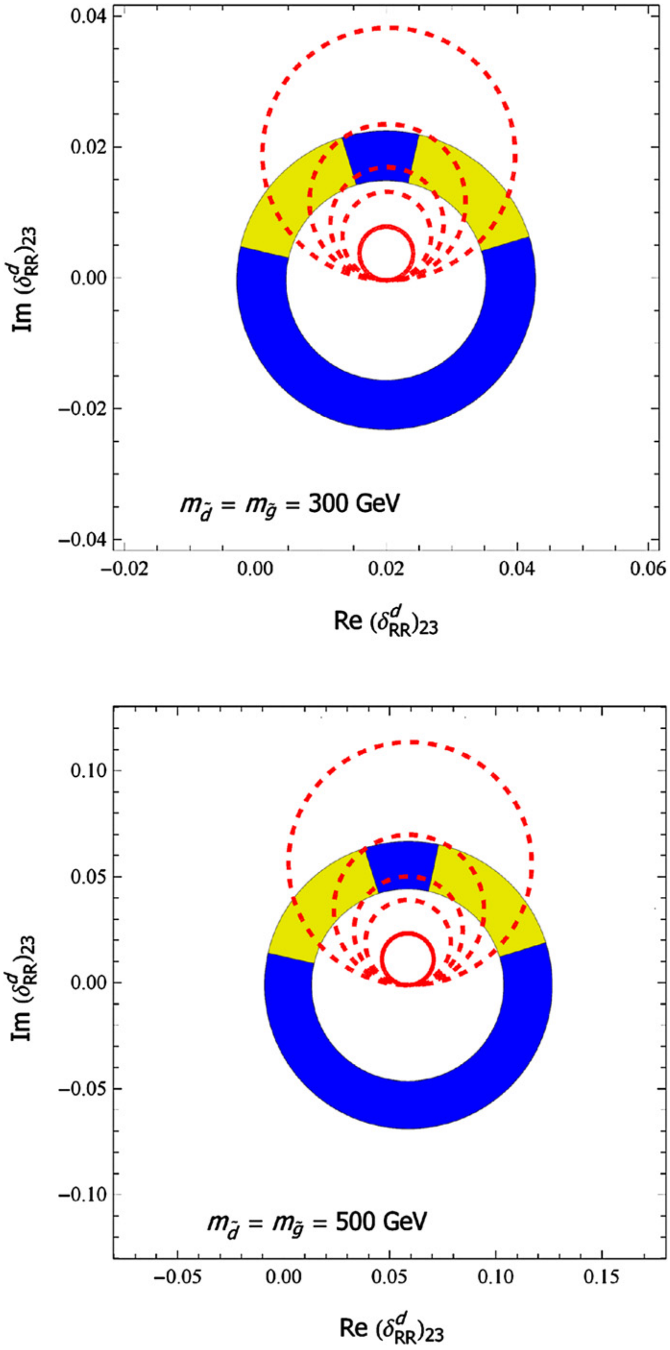

Fig. 2. Mass insertion parameter space of $(\delta_{RR}^d)_{23}$ constrained by the 2σ measurements of ΔM_s (blue/black) and the CP phase ϕ_s (yellow/light grey), see Eqs. (16), (14), plotted with $m_{\tilde{g}} = m_{\tilde{d}} = 300$ GeV (upper) and $m_{\tilde{g}} = m_{\tilde{d}} = 500$ GeV (lower). The red curves show the central value (solid curve), 1σ (inner dashed curve) and 2σ (outer dashed curve) constraints from a_{sl}^s as given in Eq. (4). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this Letter.)

$$Br(\tau \to \mu\gamma) \gtrsim 2 \times 10^{-9}\left(\frac{\tan\beta}{10}\right)^2. \tag{24}$$

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[1] Branching ratio predictions for $\tau \to e\gamma$ and the ratio $Br(\tau \to \mu\gamma)/Br(\tau \to e\gamma)$ have been presented in [21].

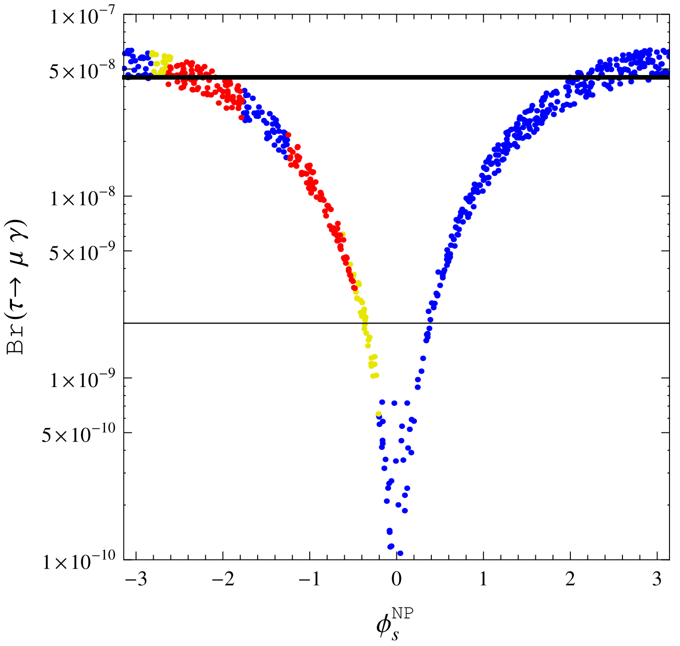

Fig. 3. The variation of the branching ratio of $\tau \to \mu\gamma$ with the new physics CP phase ϕ_s^{NP} in SUSY SU(5). The plotted points agree with the 2σ bounds of ΔM_s (blue/black), ϕ_s (yellow/light grey) and a_{sl}^s (red/dark grey). The bold horizontal line is the experimental bound of $Br(\tau \to \mu\gamma) < 4.5 \times 10^{-8}$ [22], while the narrow line shows the proposed Super-*B* factory bound $Br(\tau \to \mu\gamma) < 2 \times 10^{-9}$ [24,25]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this Letter.)

The new measurement of a_{sl}^b further constrains the range of predictions for $Br(\tau \to \mu\gamma)$. The red/dark grey dots plotted in Fig. 3 are those points which agree at the 2σ confidence level with each of ΔM_s, ϕ_s and a_{sl}^s. Including the new measurement we find that the allowed points cluster towards the middle of the yellow/light grey band, moving away from the highest and lowest rates for $\tau \to \mu\gamma$. Interestingly the majority of the preferred parameter space lies in the region between the present experimental bound for $Br(\tau \to \mu\gamma)$ and the reach of the proposed Super flavour factories [24,25].

4. Summary

In this work we have investigated the impact on the new physics parameter space of the recent measurement of the like-sign dimuon charge asymmetry at the Tevatron. Assuming that new physics enters only into B_s–$\bar{B}_s$ mixing and not into the lifetime difference, we first saw that this measurement is in reasonably good agreement with existing observations of large CP violation in the B_s system. The viable NP parameter region is further reduced by the latest Tevatron results although the two-fold ambiguity in the CP phase ϕ_s remains unresolved. If new physics present in B_s mixing is indeed responsible for the dimuon asymmetry we should expect the central value to increase in the future.

In the case of generic supersymmetric models and supersymmetric SU(5) we have explored the mass insertion parameter space and the correlation between FCNCs and LFV rates in light of the recent dimuon asymmetry measurement. The $(\delta_{RR}^d)_{23}$ mass insertion parameter space is restricted to two small regions which under the SU(5) GUT relations predict a $\tau \to \mu\gamma$ branching ratio just below the present experimental bound and within the reach of the proposed Super flavour factories.

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