Flavor Physics induced by light Z' from SO(10) GUT

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Abstract: In this talk, we show predictions of the SO(10) Grand Unified Theory (GUT), where an extra U(1)' gauge symmetry remains up to the supersymmetry (SUSY) breaking scale. The minimal setup of SO(10) GUT unifies quarks and leptons into a **16**-representational field in each generations. The setup, however, suffers from the realization of the realistic Yukawa couplings at the electroweak scale. In order to solve this problem, we introduce **10**-representational matter fields, and then the two kinds of matter fields mix each other at the SUSY breaking scale, where the extra U(1)' gauge symmetry breaks down radiatively. One crucial prediction is that the Standard Model quarks and leptons are given by the linear combinations of the fields with two different U(1)' charges. The mixing also depends on the flavor. Consequently, the U(1)' interaction becomes flavor violating, and the flavor physics is the smoking-gun signal of our GUT model. The flavor violating Z' couplings are related to the fermion masses and the CKM matrix, so that we can derive some explicit predictions in flavor physics. We especially discuss K-Kbar mixing, B_s-$B_s$bar mixing, and the (semi)leptonic decays of K and B in our model. We also study the flavor violating μ and τ decays and discuss the correlations among the physical observables in this SO(10) GUT framework.

Introduction

In SO(10) GUT, one generation of SM matter fields can be unified into one **16**-representational field.

$$\mathbf{16} \to \mathbf{10}(Q_L, u_R^c, e_R^c) + \bar{\mathbf{5}}(L_L, d_R^c) + \mathbf{1}(\nu_R^c)$$

$$\Rightarrow W_{\min} = h_{ij}\mathbf{16}_i\mathbf{16}_j\mathbf{10}_H$$

← only one Yukawa coupling

This leads to some deviation from experimental measurements of the masses and the CKM matrix.

→ Need some modification

Solutions:

- add higher-dimensional operators,
- introduce additional matter fields, ← this work
- introduce additional Higgs, …

additional interactions and **5bar** mixing

We consider that an extra U(1)' remains up to SUSY breaking scale.

→ two 5bars carry different U(1)' charges　$SO(10) \to G_{SM} \times U(1)'$

According to these, flavor violating couplings are caused. Then we search

- the predictions of this model in flavor physics
- the possibility for the observation in future experiments

Properties of this model

✓ Matter fields:

$$\mathbf{16} \to \mathbf{10}_1 + \bar{\mathbf{5}}_{-3} + \mathbf{1}_5$$

$$\mathbf{10} \to \mathbf{5}_{-2} + \bar{\mathbf{5}}_2$$

different U(1)' charges

✓ Superpotential:

$$W = W_{\min} + W_{\rm ex}$$

$$W_{\rm ex} = g_{ij}\mathbf{16}_i\mathbf{10}_j\mathbf{16}_H + \mu_{10\,ij}\mathbf{10}_i\mathbf{10}_j$$

✓ **5bar** mixing (down quark example):

$$\begin{pmatrix} d_R^{\rm SM} \\ d_R^h \end{pmatrix} = \begin{pmatrix} \hat{U}_{16}^d & \Delta U_d \\ \Delta U_d' & \hat{U}_{10}^d \end{pmatrix} \begin{pmatrix} d_R^{(16)} \\ d_R^{(10)} \end{pmatrix}$$

Note: $(\hat{U}_{16}^d)_{ik}(\hat{U}_{16}^{d*})_{jk} + (\Delta U_d)_{ik}(\Delta U_d^*)_{jk} = \delta_{ij}$

Breaks U(1)'

$$\Rightarrow \begin{pmatrix} d_{R\,i}^{(16)} & d_{R\,i}^{(10)} \end{pmatrix} \begin{pmatrix} h_{ij}v_d & g_{ij}\langle\Phi\rangle \\ 0 & \mu_{10\,ij} \end{pmatrix} \begin{pmatrix} d_{L\,j}^{(16)} \\ d_{L\,j}^{(10)} \end{pmatrix}$$

✓ Z' couplings: $\mathcal{L}_g \ni g'\hat{Z}'_\mu \left(A_{ij}^l \overline{l_L^i}\gamma^\mu l_L^j - A_{ij}^d \overline{d_R^i}\gamma^\mu d_R^j \right)$ → Tree level!

$$A_{ij}^d = 5(\hat{U}_{16}^d)_{ik}(\hat{U}_{16}^d)^*_{jk} - 2\delta_{ij}$$

$$A_{ij}^l = 5(\hat{U}_{16}^l)^*_{ik}(\hat{U}_{16}^l)_{jk} - 2\delta_{ij}$$

The other Z' couplings are diagonal $A_{ij}^{Q,u,e} = \delta_{ij}$

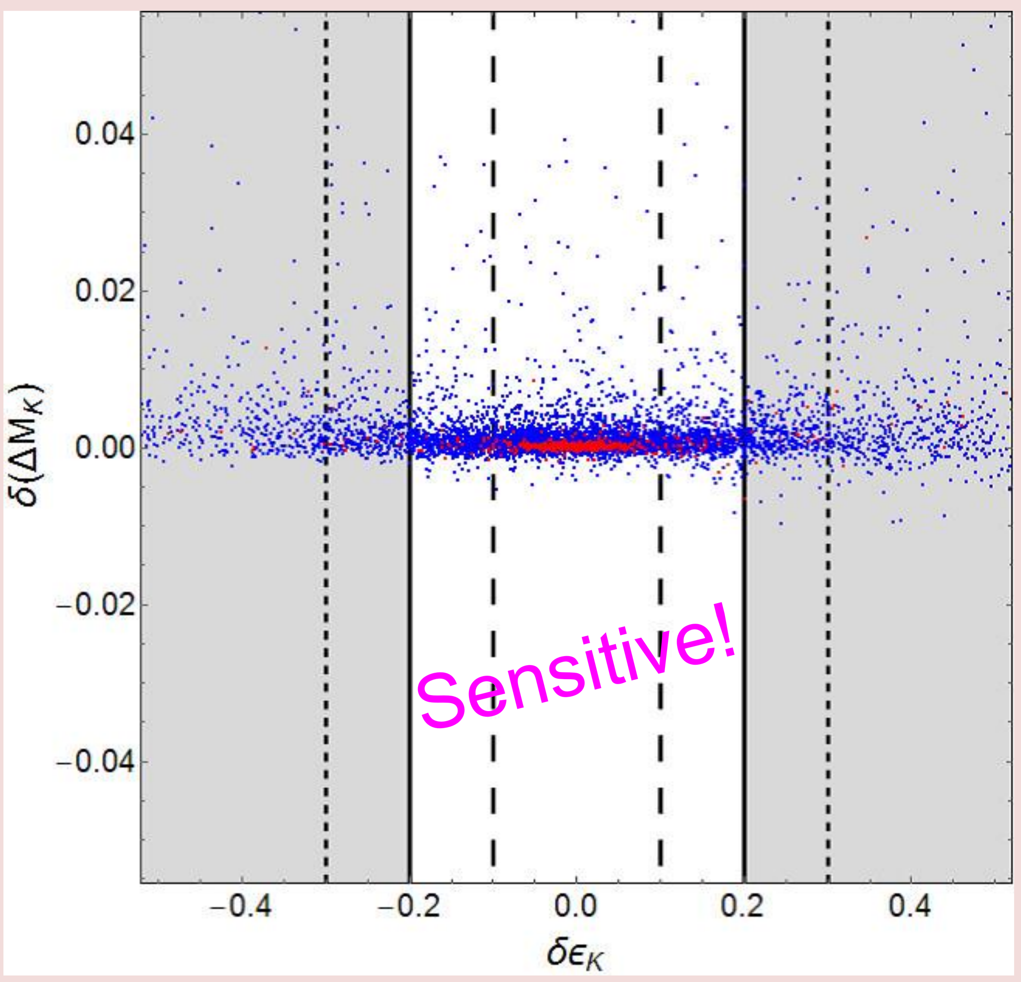
✓ Yukawa couplings (including higher-dimensional op.):

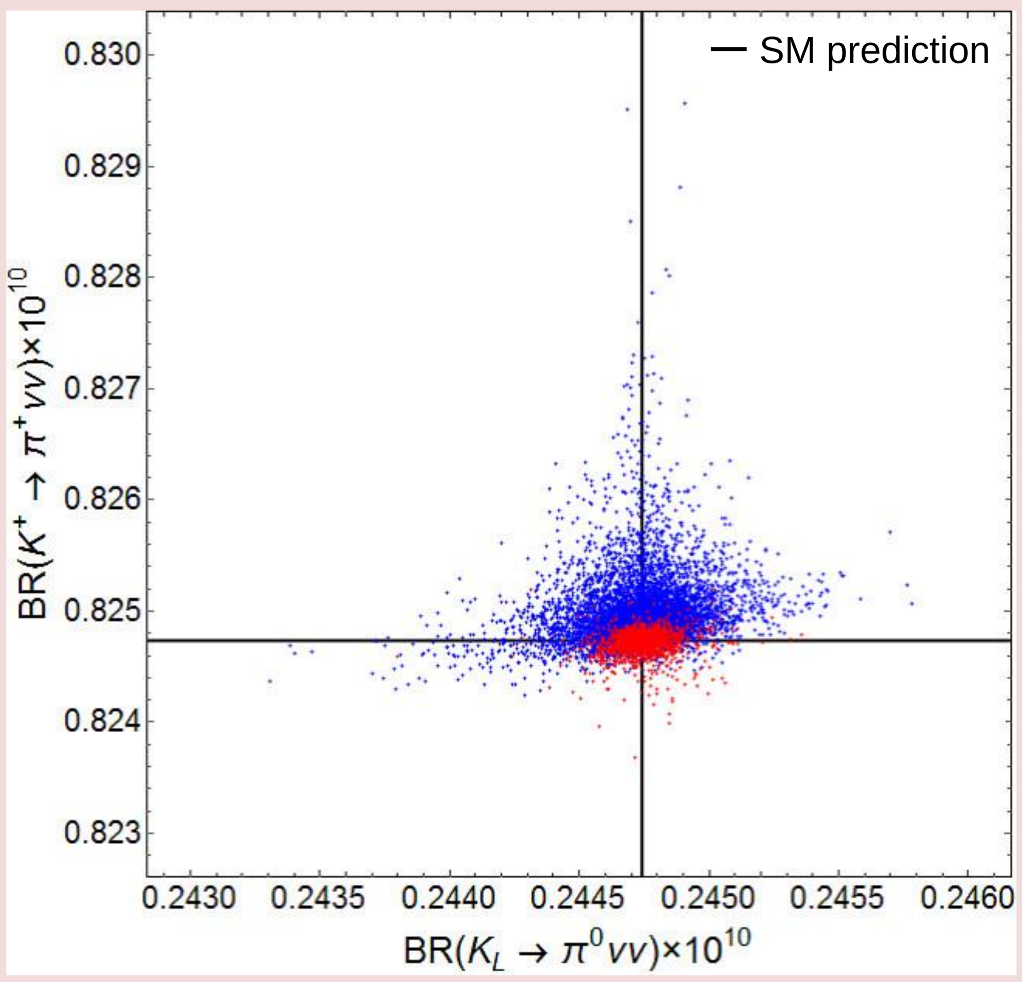
$$h_{ij}^u = \frac{m_i^u}{v^u}\delta_{ij} \qquad h_{ij}^d = \frac{m_i^d}{v^d}(V_{CKM}^*)_{ji} = (\hat{U}_{16}^d)_{ik}\left(\frac{m_k^u}{v^u}\delta_{kj} + \epsilon\, c_{kj}^d\right)$$

$$h_{ij}^l = \frac{m_i^l}{v^d}(V_R^*)_{ji} = (\hat{U}_{16}^l)_{ik}\left(\frac{m_k^u}{v^u}\delta_{kj} + \epsilon\, c_{kj}^l\right)$$

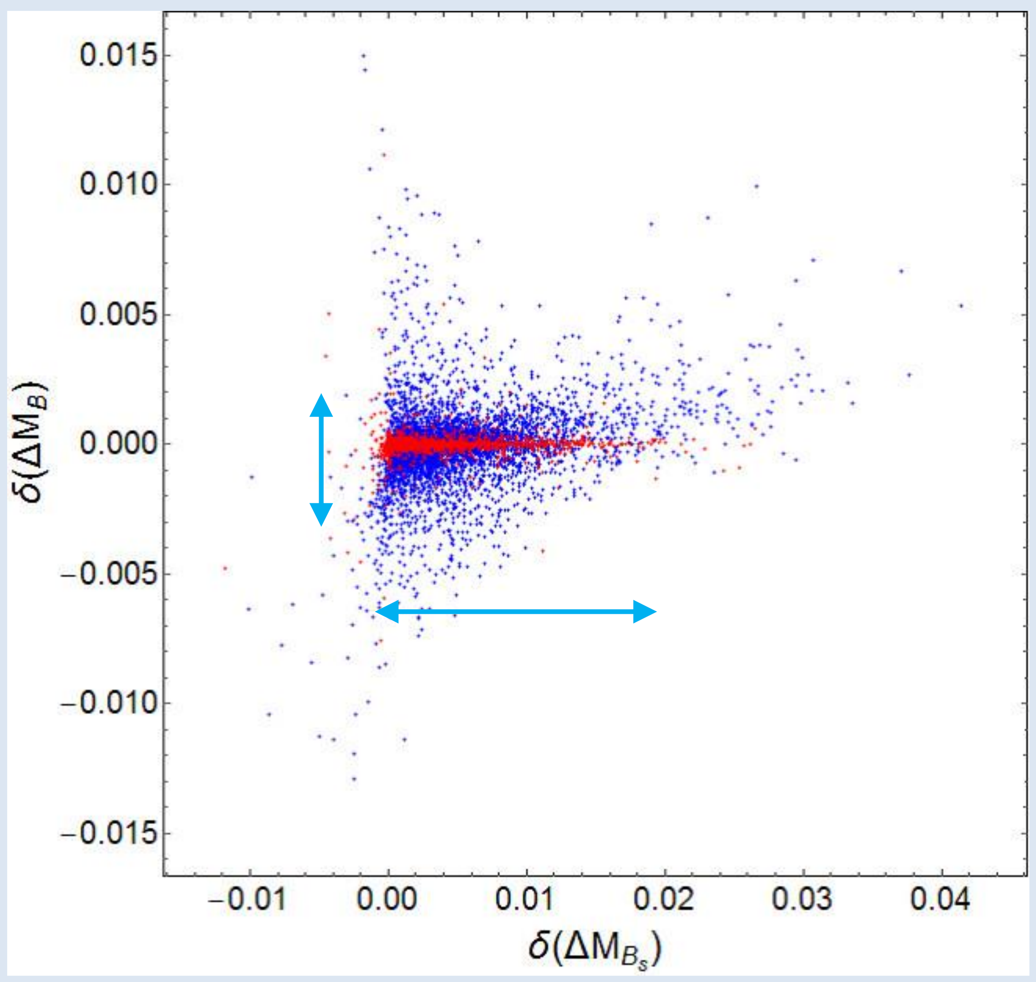
Summary

Plots: $|\epsilon\, c_{ij}^{d,l}| < 10^{-2}$, $|\epsilon\, c_{ij}^{d,l}| < 10^{-3}$　　$M_{Z'} = 100\,\text{TeV}$ case





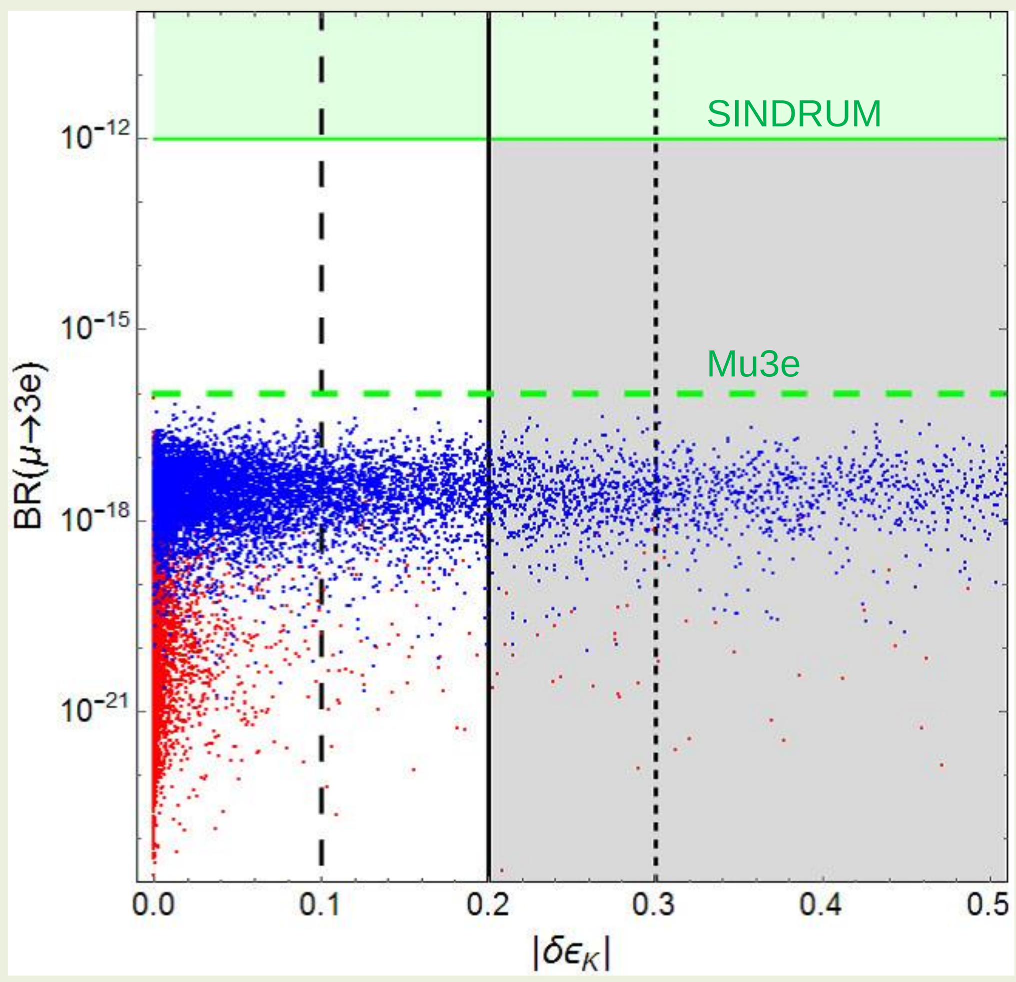
K physics

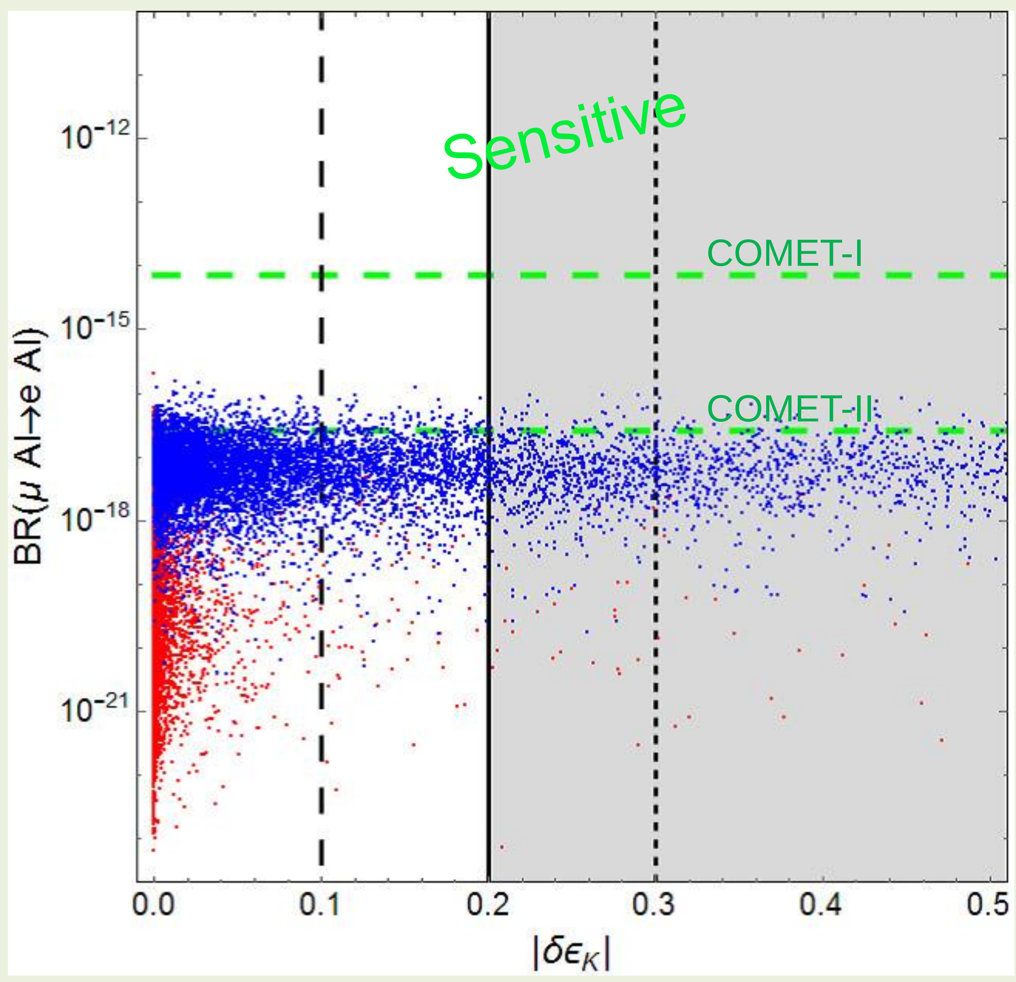


B physics

m_e	0.5110 MeV	m_K	497.611(13) MeV
m_μ	105.7 MeV	F_K	156.1(11) MeV
m_τ	1.777 GeV	$\hat{B}_K$	0.764(10)
m_d(2 GeV)	$4.8^{+0.5}_{-0.3}$ MeV	$(\Delta M_K)_{\rm exp}$	$3.484(6)\times10^{-12}$ MeV
m_s(2 GeV)	95±5 MeV	$\lvert\epsilon_K\rvert$	$(2.228(11))\times10^{-3}$
$m_b(m_b)$	4.18±0.03 GeV	BR$(K^+\to\pi^0 e^+\nu)$	5.07(4) %
$\frac{2m_s}{(m_u+m_d)}$(2 GeV)	27.5±1.0	$\tau(K^+)$	$(1.238(2))\times10^{-8}$ s
$m_c(m_c)$	1.275±0.025 GeV	$\tau(K_L)$	$(5.116(21))\times10^{-8}$ s
m_t	173.21±0.51 ± 0.71 GeV	η_1	1.87(76)
λ	$0.22543^{+0.00042}_{-0.00031}$	η_2	0.5765(65)
A	$0.8227^{+0.0066}_{-0.0136}$	η_3	0.496(47)
$\bar{\rho}$	$0.1504^{+0.0121}_{-0.0062}$	m_{B_s}	5.3663(6) GeV
$\bar{\eta}$	$0.3540^{+0.0069}_{-0.0076}$	m_B	5.2795(3) GeV
M_Z	91.1876(21) GeV	F_{B_s}	227.7 ± 6.2 MeV
M_W	80.385(15) GeV	F_B	190.6 ± 4.6 MeV
$\sin^2\theta_W$	0.23126(5)	$\hat{B}_{B_s}$	1.33(6)
G_F	$1.1663787(6)\times10^{-5}$ GeV^{-2}	$\hat{B}_B$	1.26(11)
α	1/137.036	η_B	0.55
$\alpha_s(M_Z)$	0.1193(16)	η_Y	1.012
		Γ_μ^{-1}	$2.1969811(22)\times10^{-6}$ s

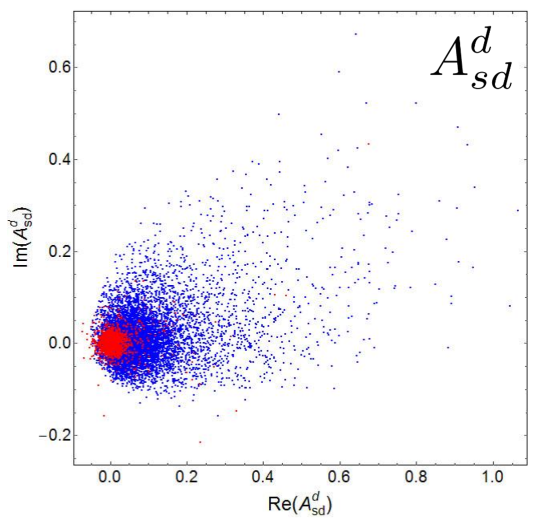
Input parameters





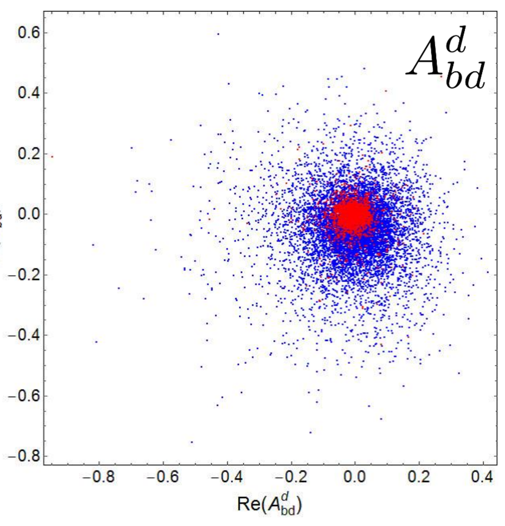
Lepton flavor violation

Flavor Violating Couplings



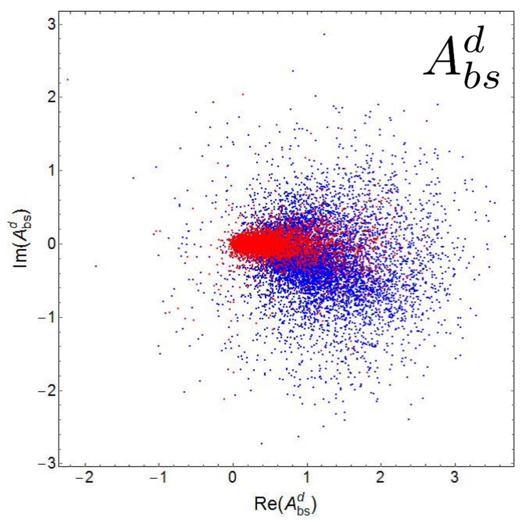
$$\mathrm{Re}(A_{sd}^d) \sim 5\tan^2\beta \frac{m_d^d m_s^d}{|v_u \epsilon\, c_{11}^d|^2}\lambda$$

$$\mathrm{Im}(A_{sd}^d) \sim 5\tan^2\beta \frac{m_d^d m_s^d}{|v_u \epsilon\, c_{11}^d|^2}\mathrm{Im}\left(\frac{v_u\epsilon\, c_{12}^{d*}}{m_c^u}\right)$$



$$A_{bd}^d \sim 5\tan^2\beta \frac{m_d^d m_b^d}{|v_u \epsilon\, c_{11}^d|^2}\left(\frac{v_u\epsilon\, c_{12}^{d*}}{m_c^u}\right)A\lambda^2$$

CKM factors: $\lambda = 0.22543,\ A = 0.8227$

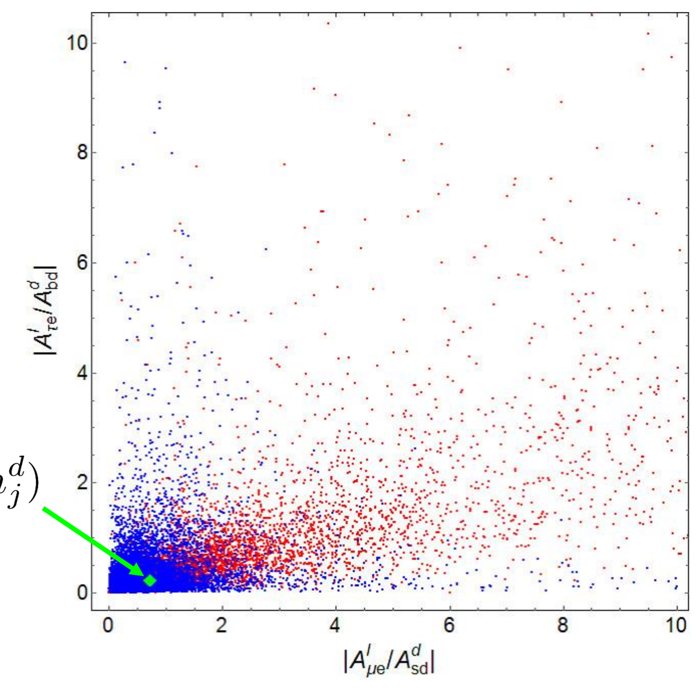


$$\mathrm{Re}(A_{bs}^d) \sim 5\tan^2\beta \frac{m_s^d m_b^d}{(m_c^u)^2}\lambda^2$$

$$\mathrm{Im}(A_{bs}^d) \sim 5\tan^2\beta \frac{m_s^d m_b^d}{|v_u \epsilon\, c_{11}^d|^2}\mathrm{Im}\left(\frac{v_u\epsilon\, c_{12}^{d*}}{m_c^u}\right)A\lambda^3$$

Fact: $A_{ij}^f \propto m_i^f m_j^f$

The value of $|A_{ij}^l/A_{ij}^d|$



Comments on tau decay

Small predictions compared with exp. bound

τ decay mode	value of BR	exp. bound (×10⁻⁸)
$e^-e^+e^-$	1.2×10^{-18}	< 2.7
$e^-\mu^+\mu^-$	4.2×10^{-19}	< 2.7
$e^+\mu^-\mu^-$	1.5×10^{-18}	< 1.7
$\mu^-e^+e^-$	3.7×10^{-15}	< 1.8
$\mu^+e^-e^-$	2.8×10^{-22}	< 1.5
$\mu^-\mu^+\mu^-$	2.7×10^{-15}	< 2.1
$e^-\pi^0$	2.2×10^{-19}	< 8.0
$\mu^-\pi^0$	1.2×10^{-15}	< 11
$e^-K_s^0$	1.2×10^{-21}	< 2.6
$\mu^-K_s^0$	6.6×10^{-18}	< 2.3