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$U(2)$ and MFV in Supersymmetry

based on:
R. Barbieri, G. Isidori, J. Jones-Pérez, P. Lodone and D.M.S.
arXiv:1105.2296

July 21, 2011 · EPS HEP 2011 · Grenoble

Minimal Flavour Violation

Assumption
Yukawas are the only spurions breaking the flavour symmetry in the quark sector

$$G_F = U(3)_{Q_L} \otimes U(3)_{U_R} \otimes U(3)_{D_R} \to U(1)_B$$

$$Y_u \sim (3, \bar{3}, 1)$$
$$Y_d \sim (3, 1, \bar{3})$$

Consequence
Flavour violation is aligned with the SM
TeV scale new physics OK with flavour bounds

[Buras et al. (200);
D'Ambrosio et al. (2002)]

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BUT

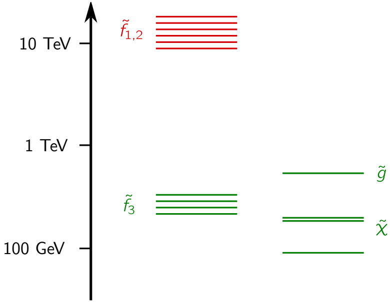
- flavour blind CP violating phases are not forbidden. Smallness of EDMs?
- no explanation for hierarchies in quark masses and mixing

[Mercolli & Smith,
Kagan et al., Paradisi & DS (2009)]

Alternatives to MFV

The third generation is special!

Effective SUSY



Improves the EDM problem

[Cohen et al. (1996), ..., Giudice et al. (2008), Barbieri, Lodone & DS (2011)]

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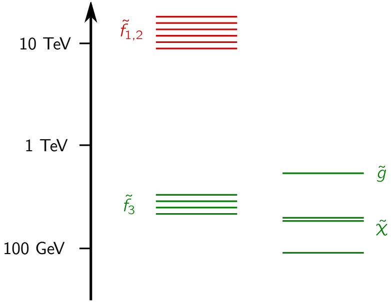

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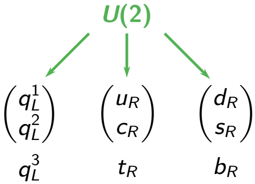
$U(2)$ SUSY flavour models



- partial explanation of hierarchies in Yukawa couplings
- Not enough flavour alignment

[Pomarol & Tommasini, Barbieri et al. (1995)]

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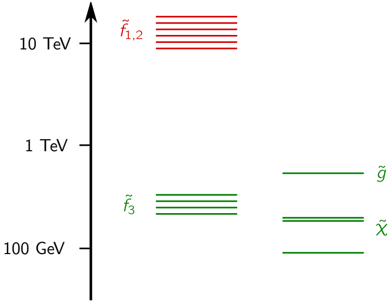

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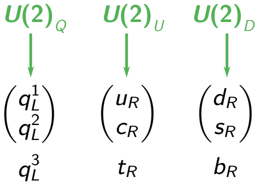

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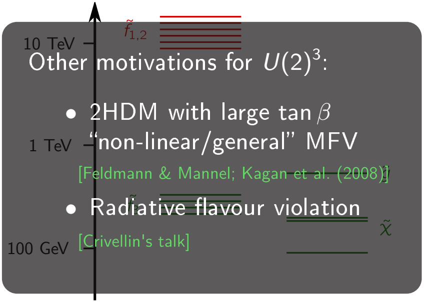

Other motivations for $U(2)^3$:

- 2HDM with large $\tan\beta$
- "non-linear/general" MFV

[Feldmann & Mannel; Kagan et al. (2008)]

- Radiative flavour violation

[Crivellin's talk]

Improves the EDM problem

[Cohen et al. (1996), ..., Giudice et al. (2008), Barbieri, Lodone & DS (2011)]

$U(2)$ SUSY flavour models

$U(2)_Q \rightarrow \begin{pmatrix} q_L^1 \\ q_L^2 \end{pmatrix}, \quad q_L^3$

$U(2)_U \rightarrow \begin{pmatrix} u_R \\ c_R \end{pmatrix}, \quad t_R$

$U(2)_D \rightarrow \begin{pmatrix} d_R \\ s_R \end{pmatrix}, \quad b_R$

- partial explanation of hierarchies in Yukawa couplings
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[Pomarol & Tommasini, Barbieri et al. (1995)]

$$G_F = U(2)_{Q_L} \otimes U(2)_{U_R} \otimes U(2)_{D_R} \rightarrow U(1)_B$$

Resulting Yukawas:

$$Y_u = y_t \left(\begin{array}{c|c} & \\ \hline & 1 \end{array}\right) \qquad Y_d = y_b \left(\begin{array}{c|c} & \\ \hline & 1 \end{array}\right)$$

$U(2)^3$ and its breaking

$$G_F = U(2)_{Q_L} \otimes U(2)_{U_R} \otimes U(2)_{D_R} \to U(1)_B$$

$$\Delta Y_u \sim (2, \bar{2}, 1)$$
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$$V \sim (2, 1, 1)$$

Resulting Yukawas:

$$Y_u = y_t \left(\begin{array}{c|c} \Delta Y_u & x_t V \\ \hline 0 & 1 \end{array} \right) \qquad Y_d = y_b \left(\begin{array}{c|c} \Delta Y_d & x_b V \\ \hline 0 & 1 \end{array} \right)$$

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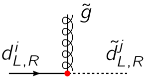
Breaking pattern:

- **minimal** (only 1 doublet)
- **weak** ($U(2)^3$ is a much better approximation than $U(3)^3$)

$U(2)^3$ breaking: consequences

$$Y_u = y_t \left(\begin{array}{c|c} \Delta Y_u & x_t V \\ \hline 0 & 1 \end{array}\right) \qquad Y_d = y_b \left(\begin{array}{c|c} \Delta Y_d & x_b V \\ \hline 0 & 1 \end{array}\right)$$

$$m^2_{\tilde{Q}} = m^2_{Q_h} \left(\begin{array}{c|c} 1 + c_{Qv} V^* V^T + c_{Qu} \Delta Y_u^* \Delta Y_u^T + c_{Qd} \Delta Y_d^* \Delta Y_d^T & x_Q e^{-i\phi_Q} V^* \\ \hline x_Q e^{i\phi_Q} V^T & m^2_{Q_l} / m^2_{Q_h} \end{array}\right)$$



$\propto (W^d_{L,R})_{ij}$

$$W^d_L = \begin{pmatrix} c_d & \kappa^* & -\kappa^* s_L e^{i\gamma} \\ -\kappa & c_d & -c_d s_L e^{i\gamma} \\ 0 & s_L e^{-i\gamma} & 1 \end{pmatrix} \qquad (W^d_R)_{ij} \approx \delta_{ij}$$

New mixing angle s_L and new phase γ in $b \to s, d$ transitions

$$Y_u = y_t \left(\begin{array}{c|c} \Delta Y_u & x_t\, V \\ \hline 0 & 1 \end{array}\right) \qquad Y_d = y_b \left(\begin{array}{c|c} \Delta Y_d & x_b\, V \\ \hline 0 & 1 \end{array}\right)$$

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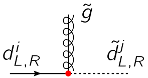

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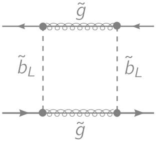
crucial feature: assumption of minimal breaking leads to MFV-like alignment

New mixing angle s_L and new phase γ in $b \to s, d$ transitions

K and B mixing



Unlike MFV: gluino contributions to meson mixing are not aligned in phase with the SM

$$\epsilon_K = \epsilon_K^{\text{SM}} \times \left(1 + x^2 F_0\right)$$

→ positive shift in ϵ_K

$$S_{\psi K_S} = \sin\left[2\beta + \arg\left(1 + x F_0 e^{-2i\gamma}\right)\right]$$

$$S_{\psi\phi} = \sin\left[2|\beta_s| - \arg\left(1 + x F_0 e^{-2i\gamma}\right)\right]$$

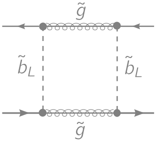
→ universal shift in B_d and B_s phases

$$\frac{\Delta M_d}{\Delta M_s} = \left(\frac{\Delta M_d}{\Delta M_s}\right)^{\text{SM}}$$

$$x e^{-2i\gamma} = \left[(W_L^d)_{33}(W_L^d)^*_{23}\right]^2$$

$$F_0\left(\frac{m^2_{\tilde{g}}}{m^2_{\tilde{b}_L}}\right) > 0$$

K and B mixing



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$$\frac{\Delta M_d}{\Delta M_s} = \left(\frac{\Delta M_d}{\Delta M_s}\right)^{\text{SM}}$$

This is a model-independent consequence of the $U(2)^3$ symmetry!
Happens also in (non-MSSM) MFV with flavour-blind phases and large $\tan\beta$

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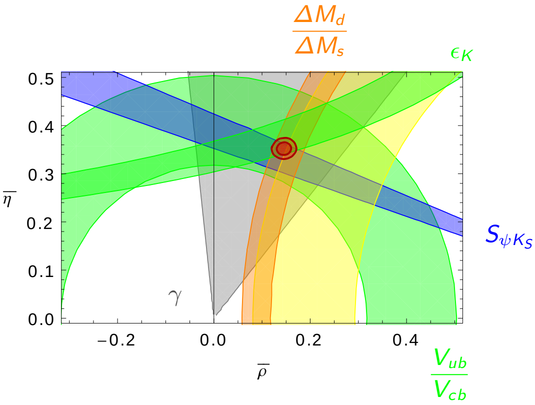
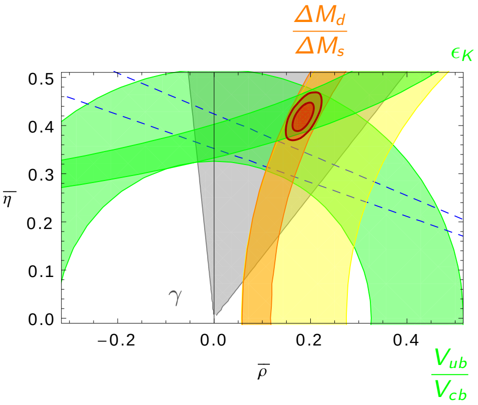
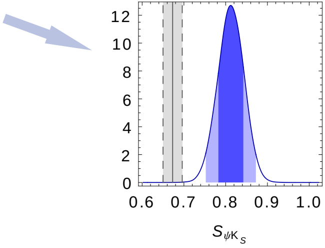
[Kagan et al. (2009)]

CKM fit: Standard Model



CKM fit: tensions





see also: Lunghi & Soni (2008, 2011)
Buras & Guadagnoli (2008)
UTfit, CKMfitters

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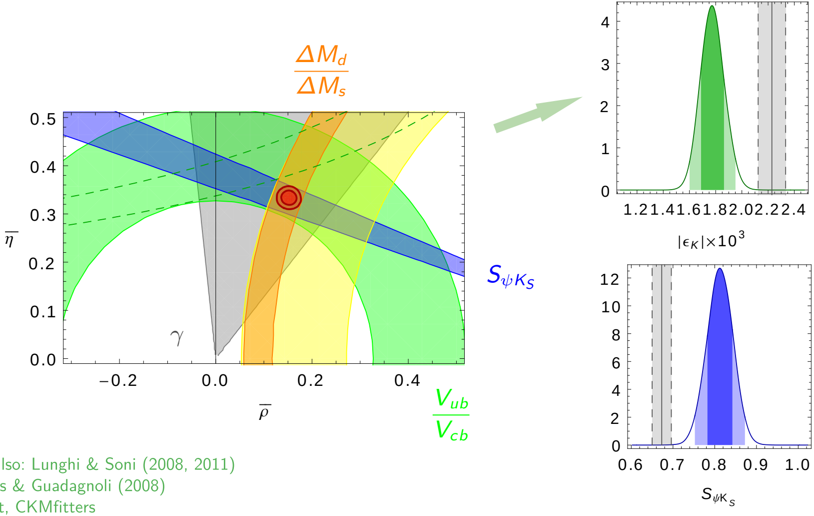

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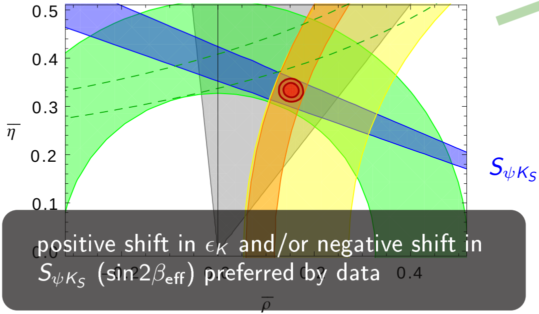
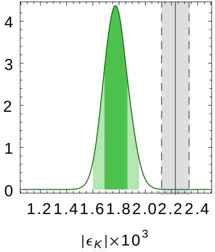
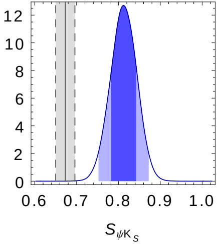


positive shift in ϵ_K and/or negative shift in $S_{\psi K_S}$ ($\sin 2\beta_{\text{eff}}$) preferred by data





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CKM fit: $U(2)^3$ solution

$$\epsilon_K = \epsilon_K^{\rm SM} \times \left(1 + x^2 F_0\right) \quad (1)$$

$$S_{\psi K_S} = \sin\left[2\beta + \arg\left(1 + x F_0 e^{-2i\gamma}\right)\right] \quad (2)$$

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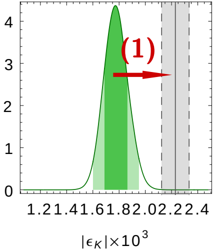
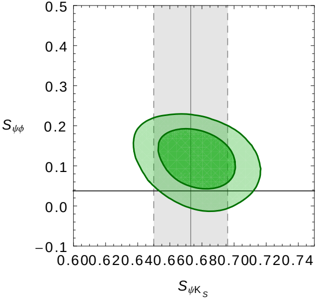
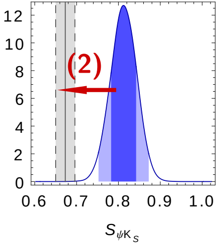
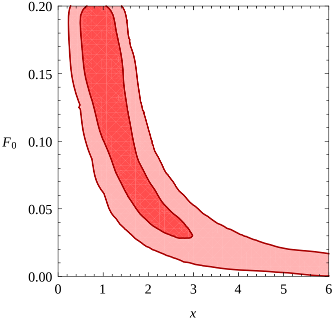


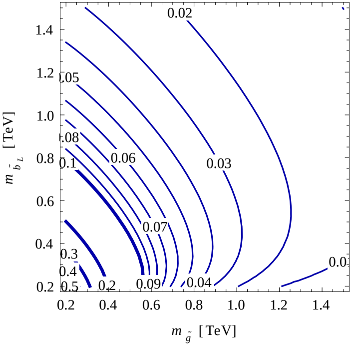


(3)



Solution of CKM tensions implies sizable $S_{\psi\phi}$





Sub-TeV sbottom and gluino masses preferred to solve CKM tension

Conclusions

Effective SUSY with a $U(2)^3$ flavour symmetry ...

- is an alternative to MFV providing a mechanism of flavour alignment
- can (partially) explain Yukawa hierarchies
- improves MFV's EDM problem
- can solve CKM tensions
- predicts positive $S_{\psi\phi}$ and sub-TeV sbottom and gluino masses
- Example implementation: 2-site deconstructed model with 3rd generation separated from 1st/2nd
- Also: interesting effects in $\Delta B = 1$ transitions (work in progress)

backup

CKM fit: inputs

$\|V_{ud}\|$	$0.97425(22)$	f_K	(155.8 ± 1.7) MeV
$\|V_{us}\|$	$0.2254(13)$	$\hat{B}_K$	0.724 ± 0.030
$\|V_{cb}\|$	$(40.89 \pm 0.70) \times 10^{-3}$	κ_ϵ	0.94 ± 0.02
$\|V_{ub}\|$	$(3.97 \pm 0.45) \times 10^{-3}$	$f_{B_s}\sqrt{\hat{B}_s}$	(291 ± 16) MeV
γ_{CKM}	$(74 \pm 11)^\circ$	ξ	1.23 ± 0.04
$\|\epsilon_K\|$	$(2.229 \pm 0.010) \times 10^{-3}$		
$S_{\psi K_S}$	0.673 ± 0.023		
ΔM_d	$(0.507 \pm 0.004)\,\text{ps}^{-1}$		
ΔM_s	$(17.77 \pm 0.12)\,\text{ps}^{-1}$		

Ugly formulae

$$V_{\mathrm{CKM}} \approx \begin{pmatrix} c_u c_d + s_u s_d\, e^{i(\alpha_d-\alpha_u)} & -c_u s_d\, e^{-i\alpha_d} + s_u c_d\, e^{-i\alpha_u} & s_u s e^{-i(\alpha_u-\xi)} \\ c_u s_d\, e^{i\alpha_d} - s_u c_d\, e^{i\alpha_u} & c_u c_d + s_u s_d\, e^{i(\alpha_u-\alpha_d)} & c_u s e^{i\xi} \\ -s_d s\, e^{i(\alpha_d-\xi)} & -s c_d e^{-i\xi} & 1 \end{pmatrix}$$

$$s = |V_{cb}| = 0.0411 \pm 0.0005$$

$$\frac{s_u}{c_u} = \frac{|V_{ub}|}{|V_{cb}|} = 0.086 \pm 0.003$$

$$s_d = -0.22 \pm 0.01$$

Ugly formulae cont'd

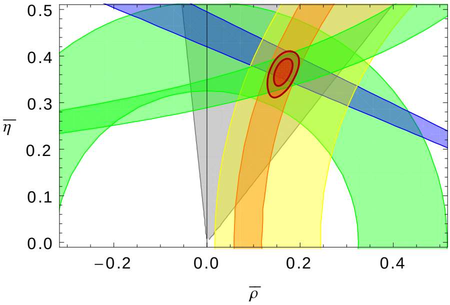
$$m^2_{\tilde{Q}} = m^2_{Q_h} \left(\begin{array}{c|c} 1 + c_{Qv} V^* V^T + c_{Qu} \Delta Y_u^* \Delta Y_u^T + c_{Qd} \Delta Y_d^* \Delta Y_d^T & x_Q e^{-i\phi_Q} V^* \\ \hline x_Q e^{i\phi_Q} V^T & m^2_{Q_l}/m^2_{Q_h} \end{array}\right)$$

$$m^2_{\tilde{d}} = m^2_{d_h} \left(\begin{array}{c|c} 1 + c_{dd} \Delta Y_d^T \Delta Y_d^* & x_d e^{-i\phi_d} \Delta Y_d^T V^* \\ \hline x_d e^{i\phi_d} V^T \Delta Y_d^* & m^2_{d_l}/m^2_{d_h} \end{array}\right)$$

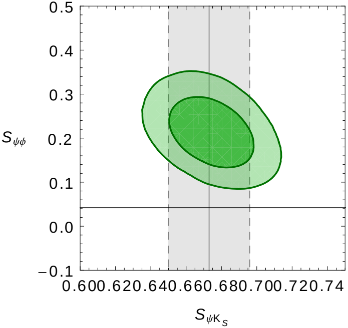
$$m^2_{\tilde{u}} = m^2_{u_h} \left(\begin{array}{c|c} 1 + c_{uu} \Delta Y_u^T \Delta Y_u^* & x_u e^{-i\phi_u} \Delta Y_u^T V^* \\ \hline x_u e^{i\phi_u} V^T \Delta Y_u^* & m^2_{u_l}/m^2_{u_h} \end{array}\right)$$

$$F_0 = \frac{2}{3} \left(\frac{g_s}{g}\right)^4 \frac{m_W^2}{m^2_{Q_3}} \frac{1}{S_0(x_t)} \left[f_0(x_g) + \mathcal{O}\left(\frac{m^2_{Q_l}}{m^2_{Q_h}}\right)\right] \qquad x_g = \frac{m^2_{\tilde{g}}}{m^2_{Q_3}}$$

$$f_0(x) = \frac{11 + 8x - 19x^2 + 26x\log(x) + 4x^2\log(x)}{3(1-x)^3}\,, \qquad f_0(1) = 1$$



$U(2)^3$ fit



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