A $U(2)^3$ flavour symmetry in Supersymmetry

Filippo Sala

Scuola Normale Superiore and INFN, Pisa

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based on:
Barbieri,Isidori,Jones-Perez,Lodone,Straub arXiv:1105.2296
Barbieri,Campli,Isidori,S,Straub arXiv:1108.5125
Barbieri,Buttazzo,S,Straub arXiv:1203.4218 and work in progress

Why is CKM so good?

Flavour: excellent agreement between data and CKM picture

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Minimal Flavour Violation paradigm

D'Ambrosio, Giudice, Isidori, Strumia 2002

$$U(3)^3 = U(3)_{Q_L} \times U(3)_{U_R} \times U(3)_{D_R}$$

$Y_u \sim (3, \bar{3}, 1)$, $Y_d \sim (3, 1, \bar{3})$ so that SM is formally invariant

Assumption: BSM also formally invariant, only with Y_u, Y_d

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Scorecard:

✓ Flavour violation controlled by the CKM matrix

$\Rightarrow$ TeV scale new physics OK with flavour bounds

× Flavour blind CP violation (smallness of EDMs)?

× $U(3)^3$ *is not* in the quark spectrum

Beyond MFV: a way to proceed

Reduce symmetry, round 1

From $U(3)^3$ to $U(2)$ Pomarol,Tommasini 1995 and Barbieri,Dvali,Hall 1995

✓ Exhibited by quark spectrum

× Too large flavour-violating effects in the RH sector

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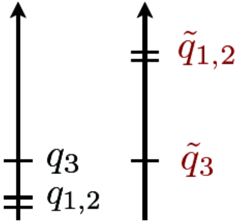
Reduce symmetry, round 2

$$U(2)^3 \quad = \quad U(2)_{Q_L} \quad \times \quad U(2)_{U_R} \quad \times \quad U(2)_{D_R}$$

$$\downarrow \qquad\qquad \downarrow \qquad\qquad \downarrow$$

$$\begin{pmatrix} q_L^1 \\ q_L^2 \end{pmatrix} \qquad \begin{pmatrix} u_R \\ c_R \end{pmatrix} \qquad \begin{pmatrix} d_R \\ s_R \end{pmatrix}$$

$$q_L^3 \qquad\qquad t_R \qquad\qquad b_R$$



SUSY with heavy $1, 2$ generations

✓ Flavour blind CP violation

(Natural and ok with collider bounds)

Scorecard:

- ✓ Small flavour-violating effects (good flavour alignment)
- ✓ Small CP-violating flavour-conserving observables (EDMs)
- ✓ $U(2)^3$ is *already* in the data! (quark Yukawas + CKM)

Breaking $U(2)^3$

Exact $U(2)^3 \quad \longrightarrow \quad m_u = m_d = m_s = m_c = 0, \; V_{CKM} = 1$

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

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- Minimal $U(2)^3$: only 1 doublet $V \sim (2, 1, 1)$ to explain CKM

Flavour observables fix $\Delta Y_{u,d}$ and V

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  Flavour observables fix $\Delta Y_{u,d}$ and V
- Generic $U(2)^3$: 2 extra doublets $V_u \sim (1, 2, 1)$, $V_d \sim (1, 1, 2)$

  Flavour observables only give upper bounds on V_u and V_d

SUSY realisation of minimal $U(2)^3$

Diagonalize Yukawas and squark mass matrices $\tilde{q}^\dagger\, \tilde{m}^2(\Delta Y, V)\, \tilde{q}$:

$$V_{\rm CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & s_u s e^{-i\delta} \\ -\lambda & 1-\lambda^2/2 & c_u s \\ -s_d s\, e^{i\beta} & -s c_d & 1 \end{pmatrix}, \qquad (\bar{u}_L\, \gamma_\mu V_{CKM} d_L)\, W_\mu$$

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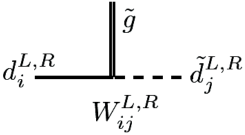


$$W^L = \begin{pmatrix} c_d & \kappa^* & -\kappa^* s_L e^{i\gamma} \\ -\kappa & c_d & -c_d s_L e^{i\gamma} \\ 0 & s_L e^{-i\gamma} & 1 \end{pmatrix}$$

$$W^R = 1 \qquad\qquad \kappa = s_d e^{i\beta}$$

- One new angle s_L and 1 new CP-violating phase γ
- Minimal breaking leads to flavour alignment

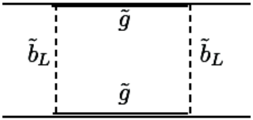
Where I am?

- Introduction/Motivations
- The $U(2)^3$ flavour symmetry in SUSY
- Phenomenology
- Conclusions

Where I am?

- Phenomenology

$\Delta F = 2$: K and B mixings



$$\epsilon_K = \epsilon_K^{\mathrm{SM},tt}\left(1+|\xi_L|^4 F_0\right) + \epsilon_K^{\mathrm{SM},tc+cc}$$

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$$\xi_L = \frac{c_d s_L}{|V_{ts}|} e^{i\gamma}, \quad F_0(m_{\tilde{b}}, m_{\tilde{g}}) > 0, \quad \phi_\Delta = \arg\left(1 + \xi_L{}^2 F_0\right)$$

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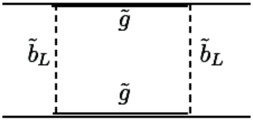

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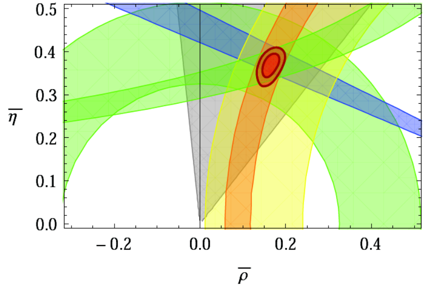
New parameters by solving CKM fit tensions



$|\xi_L| \in [0.8, 2.1]$, $\phi_\Delta \in [-9^\circ, -1^\circ]$,

$\gamma \in [-86^\circ, -25^\circ]$ or $[94^\circ, 155^\circ]$

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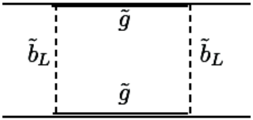

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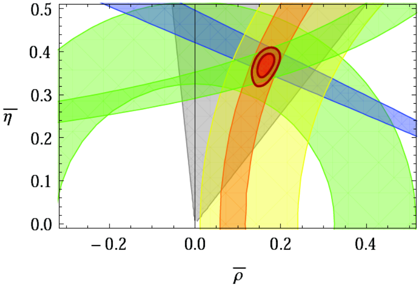

$|\xi_L| \in [0.8, 2.1]$, $\phi_\Delta \in [-9°, -1°]$,

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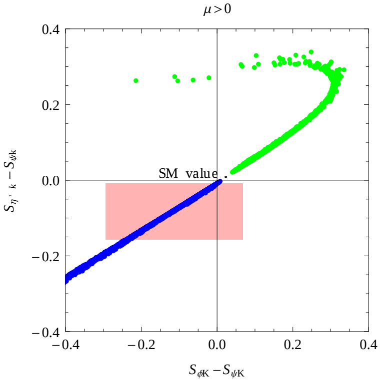
Prediction: $m_{\tilde{b}}, m_{\tilde{g}} \lesssim 1.5$ TeV

$\Delta F = 1$: selected B decays

CP asymmetries in $B \to \phi K_S,\ \eta' K_S$, $\boxed{S_{\phi K_S},\ S_{\eta' K_S}}$

$$S_f = \sin(2\beta + \phi_\Delta + \delta_f), \qquad \delta_f(\xi_L, \gamma, m_{\tilde{b}}, m_{\tilde{g}}, \mu \tan\beta - A_b)$$



Blue: $\gamma > 0$, Green: $\gamma < 0$,
Red: 1 σ experimental bound

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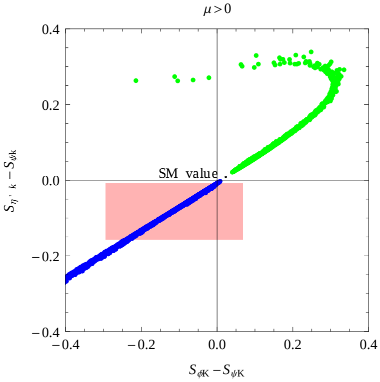

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Relevant for:

- Future improvement in sensitivity: a $5 \div 10$ factor!
- Sizeable effects with negligible flavour blind phases

Similar clean correlations also for $A_{CP}(B \to K^* \mu^+ \mu^-, B \to X_s \gamma)$

Message

Peculiar phenomenological pattern of interest for LHC

Up sector within $U(2)^3$

Prediction of no detectable effects in

- Top FCNC [$\mathrm{BR}(t \to c\gamma, cZ)$]: below future LHC sensitivity
- CPV in $D - \bar{D}$ mixing [ϕ_{12}]: below future LHCb sensitivity
- Direct CPV in D decay [$A^D_{CP}(\pi\pi, KK)$]: below per mille level

What if $A^D_{CP}(\pi\pi) - A^D_{CP}(KK) = -0.67 \pm 0.16\%$ is new physics?

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Generic $U(2)^3$ — Barbieri,Buttazzo,S,Straub work in progress

- could explain ΔA^{exp}_{CP}
- respecting all current flavour and EDMs bounds
- keeping the same null predictions for $\mathrm{BR}(t \to c\gamma, cZ)$ and ϕ_{12}

Summary of phenomenology

$\Delta F = 2$

- new phase ϕ_Δ in $B - \bar{B}$ mixing
- M^{B_d}/M^{B_s} SM-like
- no new phase in K mixing

$\Delta B = 1$

- effects *can* be large

Up

- effects cannot be large (ΔA_{CP}^D in Generic $U(2)^3$ *can*)

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- effects cannot be large (ΔA^D_{CP} in Generic $U(2)^3$ *can*)

Importance of correlated studies to distinguish between models

Conclusions

$U(2)^3$ is in the data

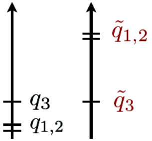
Naturally safe with flavour bounds

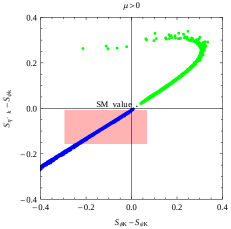
Large effects *allowed*

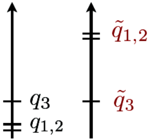
SUSY Small EDMs

Natural and ok with collider bounds

Both Peculiar phenomenology: wait for LHC







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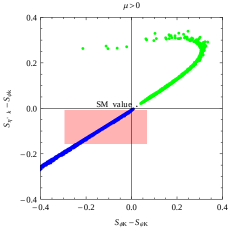

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Thank you for your attention!

Back up

$\Delta F = 1$: ϵ'_K in SUSY

A significant limit for both $U(2)^3$ and $U(3)^3$ Barbieri's talk on Monday

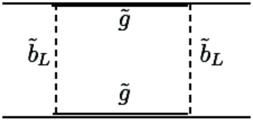
$$\mathcal{H}_{\text{eff}}^{\Delta S=1} = \frac{1}{\Lambda^2}\xi_{ds}\left(\bar{d}_L^\alpha\gamma_\mu s_L^\beta\right)\left[c_K^d\left(\bar{d}_R^\beta\gamma_\mu d_R^\alpha\right) + c_K^u\left(\bar{u}_R^\beta\gamma_\mu u_R^\alpha\right)\right]$$

$$\left|\frac{\epsilon'}{\epsilon}\right| \simeq \frac{|\text{Im}A_2|}{\sqrt{2}\,|\epsilon|\,\text{Re}A_0}, \qquad \langle(\pi\pi)_{I=2}|Q_{LR}^u + Q_{LR}^d|K\rangle = 0 \ \ *$$

$$c_K^{u,d} \lesssim 0.1 \div 0.2\left(\frac{3\,\text{TeV}}{\Lambda^2}\right)$$

$U(2)^3$+ SUSY solves the "problem"!

- box diagrams are suppressed by heavy $\tilde{u}$, $\tilde{d}$



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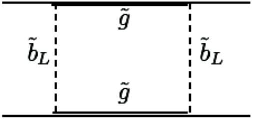
CP asymmetry in $B \to \psi\phi$



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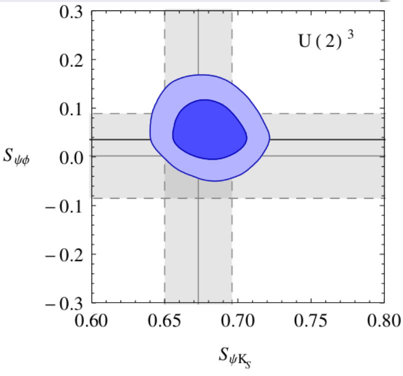
$S_{\psi\phi} = \sin\left(2|\beta_s| - \phi_\Delta\right)$

- LHCb 2 orders of magnitude improvement in sensitivity!
- Solving CKM fit tensions keep prediction $m_{\tilde{b}}, m_{\tilde{g}} \lesssim 1.5\,\mathrm{TeV}$



Leptons $U(2)^2$

See also Blankenburg, Isidori, Jones-Pérez 1204.0688

$U(2)_\ell \times U(2)_e$ broken by $\Delta Y_e \sim (2, \bar{2})$ and $V_e \sim (2, 1)$

Assumptions:

- Charged leptons behave $\sim$ quarks, Y_ν and M_ν responsible for neutrino masses and mixings
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$$c_\tau \zeta_{i\tau} m_\tau \left(\bar{e}_{Li} \sigma_{\mu\nu} \tau_R\right) eF_{\mu\nu}$$

$$c_\mu \zeta_{e\mu} m_\mu \left(\bar{e}_L \sigma_{\mu\nu} \mu_R\right) eF_{\mu\nu}$$

$$c_j \zeta_{ij} = \frac{g^2}{128\pi^2} \frac{W_L^{i3*} W_L^{j3}}{\widetilde{m}^2} \tan\beta$$

$$[\bar{\ell}_L^i W_L^{ij} \tilde{\ell}_L^j] \tilde{W}$$

Stronger bounds from $\mu \to e\gamma$, $\tau \to \mu\gamma$

$$\frac{|W_L^{23*} W_L^{13}|}{|V_{ts} V_{td}^*|} < 0.6 \times \left[\frac{m_{\tilde{\tau}_L}}{500\ \text{GeV}}\right]^2 \left[\frac{10}{\tan\beta}\right]$$

$$\frac{|W_L^{33*} W_L^{13}|}{|V_{tb} V_{td}^*|} < 1.2 \times \left[\frac{m_{\tilde{\tau}_L}}{500\ \text{GeV}}\right]^2 \left[\frac{10}{\tan\beta}\right]$$

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