Direct CP violation in charm and flavor mixing beyond the SM

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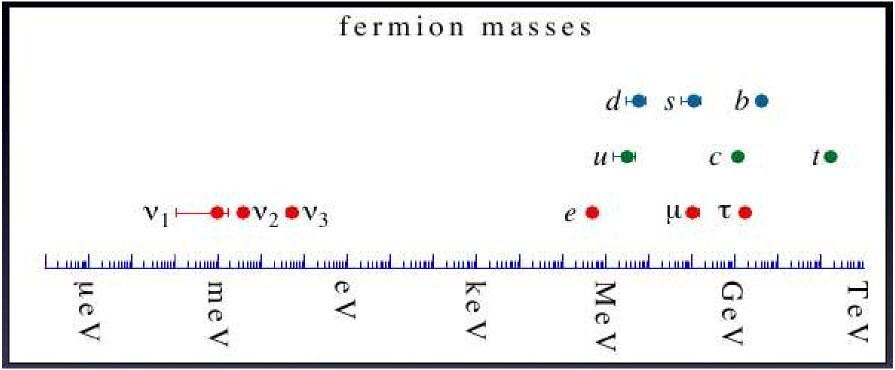
Open questions

1. **Which is the underlying mechanism regulating the EWSB?**
2. **Which is the connection between EWSB and flavor physics?**
3. **Are there new flavor symmetries beyind the puzzling fermion mass spectrum?**
4. **Are there new flavor violating interactions not governed by the SM Yukawas? That is, to which extent the MFV hypothesis is valid?**
5. **Do the new sources of CPV accounting for the BAU have an impact on flavor physics and/or EDMs?**
6. **Which is the role of flavor physics in the LHC era?**
7. **Do we expect to understand the (SM and NP) flavor puzzles through the interplay of flavor physics and the LHC?**
8. **......**



$$|V_{CKM}| \sim \begin{pmatrix} 1 & \lambda_c & \lambda_c^3 \\ \lambda_c & 1 & \lambda_c^2 \\ \lambda_c^3 & \lambda_c^2 & 1 \end{pmatrix}, \quad |V_{PMNS}| \simeq \begin{pmatrix} 0.79-0.86 & 0.50-0.61 & 0.0-0.2 \\ 0.25-0.53 & 0.47-0.73 & 0.56-0.79 \\ 0.21-0.51 & 0.42-0.69 & 0.61-0.83 \end{pmatrix}_{3\sigma}$$

Hierarchical **Anarchic / Tribimaximal**

Flavor Physics within the SM

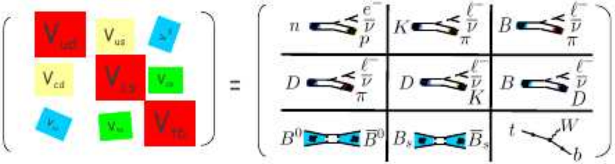
- $\mathcal{L}^{\rm SM}_{Kinetic+Gauge} + \mathcal{L}^{\rm SM}_{Higgs}$ has a large $U(3)^5$ global **flavour symmetry**

$$\mathbf{G} = \mathbf{U(3)^5} = \mathbf{U(3)_u} \otimes \mathbf{U(3)_d} \otimes \mathbf{U(3)_Q} \otimes \mathbf{U(3)_e} \otimes \mathbf{U(3)_L}$$

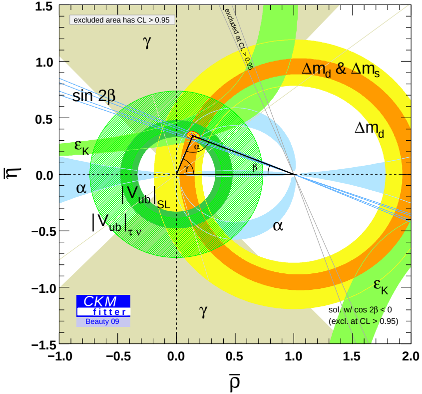
- $\mathcal{L}_{\rm Yukawa} = \bar{Q}_L \mathbf{Y_D} D_R \phi + \bar{Q}_L \mathbf{Y_U} U_R \tilde{\phi} + \bar{L}_L \mathbf{Y_L} E_R \phi + h.c$ break G down to

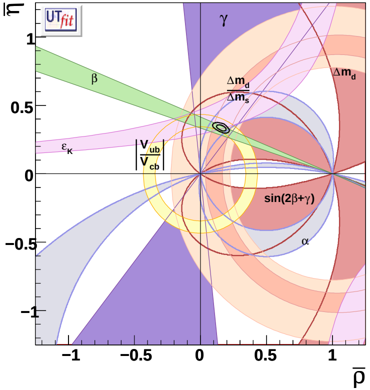
$$\mathbf{G} \rightarrow \mathbf{U(1)_B} \times \mathbf{U(1)_e} \times \mathbf{U(1)_\mu} \times \mathbf{U(1)_\tau}$$

- **CKM matrix**: $Y_U = V_{CKM} \times \mathrm{diag}(y_u, y_c, y_t)$ for $\mathbf{Y_D} = \mathrm{diag}(y_d, y_s, y_b)$

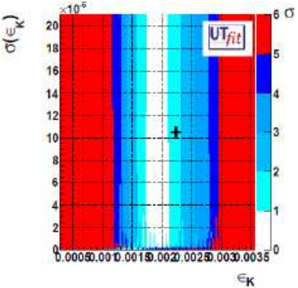
$V_{CKM} =$ 

Messages from the B-factories

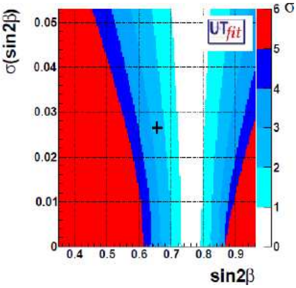




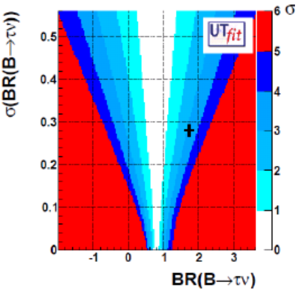
"Very likely, flavour and CP violation in FC processes are dominated by the CKM mechanism" (Nir)



fit vs. exp. $\approx -1.7\sigma$



fit vs. exp. $\approx +2.6\sigma$

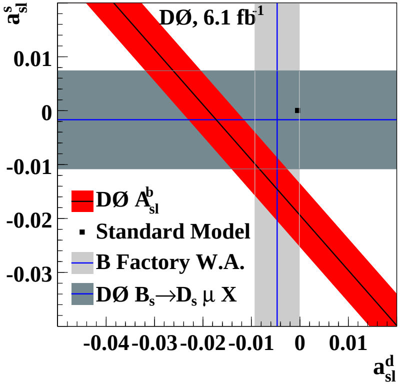


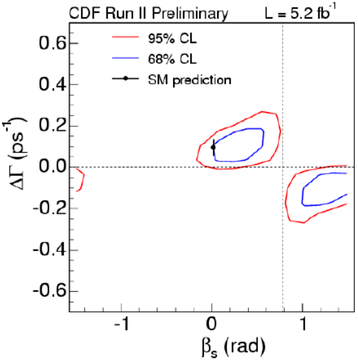
fit vs. exp. $\approx -3.2\sigma$

Similar conclusions from the CKMfitter collaboration ('10)

1. These "UT tension" are interesting but not significant yet.
2. To monitor the impact of BSM scenarios on the UT analyses.
3. To monitor the implications of possible solutions of the "UT tension" in BSM scenarios.

CPV in B_s mixing





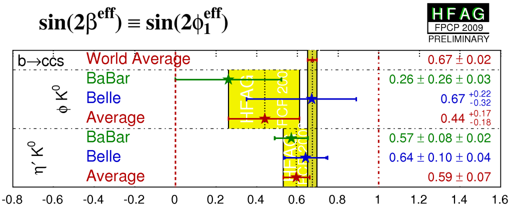
$$A^q_{\rm SL} \equiv \frac{\Gamma(\bar{B}_q \to l^+ X) - \Gamma(B_q \to l^- X)}{\Gamma(\bar{B}_q \to l^+ X) + \Gamma(B_q \to l^- X)} \,,$$

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

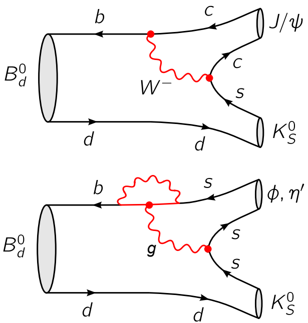
New Physics in the B_s mixing phase?

- In the SM, $(\sin 2\beta)_{\psi K_S} \approx (\sin 2\beta)_{\phi K_S} \approx (\sin 2\beta)_{\eta' K_S}$
- $B_d \to \psi K_S$ dominated by tree level, ϕK_S and $\eta' K_S$ are loop-induced

$\boxed{\text{Data indicate } S_{\phi K_S} < S_{\eta' K_S} < S_{\psi K_S}}$



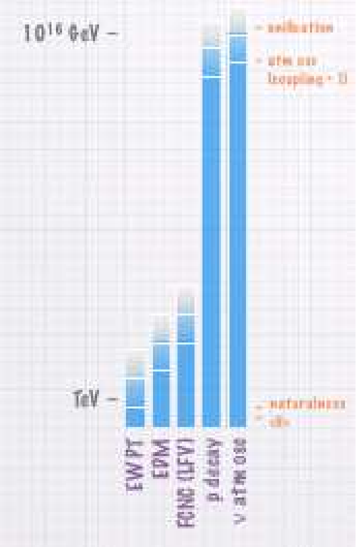
[adapted from HFAG]



$\boxed{\text{New physics in the decay amplitudes?}}$

$\boxed{\text{The SuperB will tell us...}}$

- **Gravity** $\Longrightarrow$ $\Lambda_{\text{Planck}} \sim 10^{18-19}\,\mathrm{GeV}$
- **Neutrino masses** $\Longrightarrow$ $\Lambda_{\text{see-saw}} \lesssim 10^{15}\,\mathrm{GeV}$
- **BAU**: evidence of CPV beyond SM
  - Electroweak Baryogenesis $\Longrightarrow$ $\Lambda_{NP} \lesssim \mathrm{TeV}$
  - Leptogenesis $\Longrightarrow$ $\Lambda_{\text{see-saw}} \lesssim 10^{15}\,\mathrm{GeV}$
- **Hierarchy problem**: $\Longrightarrow$ $\Lambda_{NP} \lesssim \mathrm{TeV}$
- **Dark Matter** $\Longrightarrow$ $\Lambda_{NP} \lesssim \mathrm{TeV}$



SM = effective theory at the EW scale

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum_{d\geq 5} \frac{c_{ij}^{(d)}}{\Lambda_{NP}^{d-4}}\, O_{ij}^{(d)}$$

$$\mathbf{BR}(\ell_i \to \ell_j \gamma) \sim \frac{1}{\Lambda_{NP}^4}$$

- $\mathcal{L}_{\text{eff}}^{d=5} = \frac{y_\nu^{ij}}{\Lambda_{\text{see-saw}}} L_i L_j \phi\phi$,
- $\mathcal{L}_{\text{eff}}^{d=6}$ generates FCNC operators

The NP flavor problem

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \sum_{d=6} \frac{c_{ij}^{(6)}}{\Lambda_{NP}^2} O_{ij}^{(6)}$$

[Isidori, Nir, Perez '10]

Operator	Bounds on Λ (TeV)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar s_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ε_K
$(\bar s_R d_L)(\bar s_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ε_K
$(\bar c_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p \rvert, \phi_D$
$(\bar c_R u_L)(\bar c_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p \rvert, \phi_D$
$(\bar b_L \gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	Δm_{B_d}; $S_{B_d \to \psi K}$
$(\bar b_R d_L)(\bar b_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	Δm_{B_d}; $S_{B_d \to \psi K}$
$(\bar b_L \gamma^\mu s_L)^2$	1.1×10^2	1.1×10^2	7.6×10^{-5}	7.6×10^{-5}	Δm_{B_s}
$(\bar b_R s_L)(\bar b_L s_R)$	3.7×10^2	3.7×10^2	1.3×10^{-5}	1.3×10^{-5}	Δm_{B_s}

$\Downarrow$

“Generic” flavor violating sources at the TeV scale are excluded

MFV & the NP flavor problem

- SM without Yukawa interactions: $U(3)^5$ global **flavour symmetry**

$$\mathbf{U(3)_u \otimes U(3)_d \otimes U(3)_Q \otimes U(3)_e \otimes U(3)_L}$$

- Yukawa interactions break this symmetry
- Proposal for any New Physics model:

Yukawa structures as the only sources of flavour violation

$$\Downarrow$$

Minimal Flavour Violation [D'Ambrosio et al. '02]

Notice that MFV allows new "flavour blind"CPV phases!

[Kagan et al. '09] (model-independent)
[Ellis et al. '07] (SUSY)
[Colangelo et al., '08], [Smith et al. '09] (SUSY)
[Altmannshofer et al., '08,'09], [P.P & Straub, '09] (SUSY)
[Buras et al., '10,'10] (2HDM)

MFV & the NP flavor problem

$$(c^{\Delta F=1}_{\rm MFV})_{ij} \sim V^\star_{ti} V_{tj}\,, \qquad (c^{\Delta F=2}_{\rm MFV})_{ij} \sim (V^\star_{ti} V_{tj})^2$$

$\Delta F = 1,2$ MFV operators	Λ(TeV)	Observables
$H^\dagger\left(\overline{D}_R Y^{d\dagger} Y^u Y^{u\dagger} \sigma_{\mu\nu} Q_L\right)(eF_{\mu\nu})$	6.1 TeV	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
$\frac{1}{2}(\overline{Q}_L Y^u Y^{u\dagger}\gamma_\mu Q_L)^2$	5.9 TeV	ϵ_K, Δm_{B_d}, Δm_{B_s}
$H^\dagger_D\left(\overline{D}_R Y^{d\dagger} Y^u Y^{u\dagger} \sigma_{\mu\nu} T^a Q_L\right)(g_s G^a_{\mu\nu})$	3.4 TeV	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
$\left(\overline{Q}_L Y^u Y^{u\dagger}\gamma_\mu Q_L\right)(\overline{E}_R\gamma_\mu E_R)$	2.7 TeV	$B \to X_s\ell^+\ell^-$, $B_s \to \mu^+\mu^-$
$\left(\overline{Q}_L Y^u Y^{u\dagger}\gamma_\mu Q_L\right)(eD_\mu F_{\mu\nu})$	1.5 TeV	$B \to X_s\ell^+\ell^-$

Observable	Experiment	MFV prediction	SM prediction
$\mathcal{A}_{\rm CP}(B_s \to \psi\phi)$	[0.10, 1.44] @ 95% CL	0.04(5)	0.04(2)
$\mathcal{A}_{\rm CP}(B \to X_s\gamma)$	$< 6\%$ @ 95% CL	< 0.02	< 0.01
$\mathcal{B}(B_d \to \mu^+\mu^-)$	$< 1.8 \times 10^{-8}$	$< 1.2 \times 10^{-9}$	$1.3(3) \times 10^{-10}$
$\mathcal{B}(B \to X_s\tau^+\tau^-)$	–	$< 5 \times 10^{-7}$	$1.6(5) \times 10^{-7}$
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})$	$< 2.6 \times 10^{-8}$ @ 90% CL	$< 2.9 \times 10^{-10}$	$2.9(5) \times 10^{-11}$

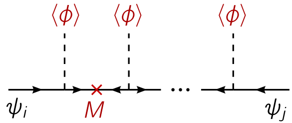
[D'Ambrosio et al. '02; Hurth et al. '08, Isidori, Nir & Perez '10]

SM vs. NP flavor problems

1. MFV is not a theory of flavour and it has not been probed yet.
2. Can the SM and NP flavour problems have a common explanation?

- **Froggat-Nielsen '79: Hierarchies from SSB of a Flavour Symmetry**

$$\epsilon = \frac{\langle\phi\rangle}{M} \ll 1 \Rightarrow Y_{ij} \propto \epsilon^{(a_i+b_j)}$$



- **Flavor protection from flavor models:** [Lalak, Pokorski & Ross '10]

Operator	$U(1)$	$U(1)^2$	$SU(3)$	MFV
$(\overline{Q}_L X^Q_{LL} Q_L)_{12}$	λ	λ^5	λ^3	λ^5
$(\overline{D}_R X^D_{RR} D_R)_{12}$	λ	λ^{11}	λ^3	$(y_d y_s) \times \lambda^5$
$(\overline{Q}_L X^D_{LR} D_R)_{12}$	λ^4	λ^9	λ^3	$y_s \times \lambda^5$

- Is the this flavor protection enough?
- Is it possible to disentangle among different flavour models by means of their predicted pattern of deviation w.r.t. the SM predictions in flavour physics?

NP search strategies

- **High-energy frontier: A unique effort to determine the NP scale**

- **High-intensity frontier (flavor physics): A collective effort to determine the flavor structure of NP**

Where to look for New Physics at the low energy?

- **Processes very suppressed or even forbidden in the SM**
  - FCNC processes ($\mu \to e\gamma$, $\tau \to \mu\gamma$, $B^0_{s,d} \to \mu^+\mu^-$, $K \to \pi\nu\bar{\nu}$)
  - CPV effects in the electron/neutron EDMs, $d_{e,n}$...
  - FCNC & CPV in $B_{s,d}$ decay/mixing & D mixing amplitudes

- **Processes predicted with high precision in the SM**
  - EWPO as $(g-2)_\mu$: $a_\mu^{exp} - a_\mu^{SM} \approx (3 \pm 1) \times 10^{-9}$, a discrepancy at 3σ!
  - LU in $R_M^{e/\mu} = \Gamma(M \to e\nu)/\Gamma(M \to \mu\nu)$ with $M = \pi, K$

Experimental status

Observable	SM prediction	Theory error	Present result	Future error	Future Facility
$S_{B_s\to\psi\phi}$	**0.036**	≤ 0.01	$\lesssim \|0.2\|$	0.01	**LHCb**
$S_{B_d\to\phi K}$	$\sin(2\beta)$	≤ 0.05	0.44 ± 0.18	0.1	LHCb
$A^d_{\rm SL}$	-5×10^{-4}	10^{-4}	$-(5.8\pm 3.4)10^{-3}$	10^{-3}	LHCb
$A^s_{\rm SL}$	2×10^{-5}	$< 10^{-5}$	$(1.6\pm 8.5)10^{-3}$	10^{-3}	LHCb
$A_{CP}(b\to s\gamma)$	< 0.01	< 0.01	-0.012 ± 0.028	0.005	Super-B
$\mathcal{B}(B\to\tau\nu)$	1×10^{-4}	$20\%\to 5\%$	$(1.73\pm 0.35)10^{-4}$	5%	Super-B
$\mathcal{B}(B\to\mu\nu)$	4×10^{-7}	$20\%\to 5\%$	$< 1.3\times 10^{-6}$	6%	Super-B
$\mathcal{B}(B_s\to\mu^+\mu^-)$	3×10^{-9}	$20\%\to 5\%$	$< 1.1\times 10^{-8}$	10%	**LHCb**
$\mathcal{B}(B_d\to\mu^+\mu^-)$	1×10^{-10}	$20\%\to 5\%$	$< 1.5\times 10^{-8}$	**[?]**	**LHCb**
$B\to K\nu\bar\nu$	4×10^{-6}	$20\%\to 10\%$	$< 1.4\times 10^{-5}$	20%	Super-B
$\|q/p\|_{D-\rm mixing}$	1	$< 10^{-3}$	$(0.86^{+0.18}_{-0.15})$	0.03	Super-B
ϕ_D	0	$< 10^{-3}$	$-(9.6^{+8.3}_{-9.5})^\circ$	2°	Super-B
$\mathcal{B}(K^+\to\pi^+\nu\bar\nu)$	8.5×10^{-11}	8%	$(1.73^{+1.15}_{-1.05})10^{-10}$	10%	K factory
$\mathcal{B}(K_L\to\pi^0\nu\bar\nu)$	2.6×10^{-11}	10%	$< 2.6\times 10^{-8}$	[?]	K factory

[Altmannshofer, Buras, Gori, Paradisi, and Straub, '09; Isidori, Nir, and Perez, '10]

Superstars of 2011-2013 in flavour physics: $\mu\to e\gamma$, $B_s\to\psi\phi$, $B_{s,d}\to\mu^+\mu^-$

$B \to K^* \ell^+ \ell^-$ observables [Altmannshofer, P.P., Straub, '11]

Observable	Experiment		SM prediction	
$10^4 \times \mathrm{BR}(B \to X_s \gamma)$	3.55 ± 0.26	[26]	3.15 ± 0.23	[27]
$S_{K^*\gamma}$	-0.16 ± 0.22	[26]	(-2.3±1.6)%	[31]
$10^6 \times \mathrm{BR}(B \to X_s \ell^+ \ell^-)_{[1,6]}$	1.63 ± 0.50	[37, 38]	1.59 ± 0.11	[42]
$10^7 \times \mathrm{BR}(B \to X_s \ell^+ \ell^-)_{>14.4}$	4.3 ± 1.2	[37, 38]	2.3 ± 0.7	[10]
$10^7 \times \mathrm{BR}(B \to K^* \ell^+ \ell^-)_{[1,6]}$	1.71 ± 0.22	[7, 49, 68]	2.28 ± 0.63	
$10^7 \times \mathrm{BR}(B \to K^* \ell^+ \ell^-)_{[14.18,16]}$	1.11 ± 0.13	[7, 49, 68]	1.13 ± 0.33	
$10^7 \times \mathrm{BR}(B \to K^* \ell^+ \ell^-)_{[16,19]}$	1.35 ± 0.15	[7, 49, 68]	1.34 ± 0.51	
$\langle F_L \rangle (B \to K^* \ell^+ \ell^-)_{[1,6]}$	0.61 ± 0.09	[7, 49, 51]	0.77 ± 0.04	
$\langle F_L \rangle (B \to K^* \ell^+ \ell^-)_{[14.18,16]}$	0.28 ± 0.09	[7, 49, 51]	0.37 ± 0.17	
$\langle F_L \rangle (B \to K^* \ell^+ \ell^-)_{[16,19]}$	0.23 ± 0.08	[7, 49, 51]	0.34 ± 0.22	
$\langle A_{FB} \rangle (B \to K^* \ell^+ \ell^-)_{[1,6]}$	-0.04 ± 0.12	[7, 49, 51]	0.03 ± 0.02	
$\langle A_{FB} \rangle (B \to K^* \ell^+ \ell^-)_{[14.18,16]}$	-0.50 ± 0.07	[7, 49, 51]	-0.41 ± 0.11	
$\langle A_{FB} \rangle (B \to K^* \ell^+ \ell^-)_{[16,19]}$	-0.38 ± 0.10	[7, 49, 51]	-0.35 ± 0.11	
$\langle S_3 \rangle (B \to K^* \ell^+ \ell^-)_{[1,6]}$	0.27 ± 0.56	[51]	$(-0.3 \pm 1.1)\,10^{-2}$	
$\langle A_9 \rangle (B \to K^* \ell^+ \ell^-)_{[1,6]}$	0.09 ± 0.39	[51]	$(1.5 \pm 2.4)\,10^{-4}$	

Time-integrated CP asymmetries in $D^0 \to K^+K^-(\pi^+\pi^-)$

- **Experiment:** $\Delta a_{CP} = a_{K^+K^-} - a_{\pi^+\pi^-}$

$$\begin{aligned} \Delta a_{CP} &= -(0.82 \pm 0.21 \pm 0.11) \quad \text{[LHCb '11]} \\ \Delta a_{CP} &= -(0.65 \pm 0.18) \quad \text{[LHCb '11, CDF '11, Belle '08 and BaBar '07]} \end{aligned}$$

$$a_f \equiv \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to f)}, \quad f = K^+K^-, \pi^+\pi^-$$

- **Theory**

SCS decay amplitude $A_f(\bar{A}_f)$ of D^0 $(\bar{D}^0)$ to a CP eigenstate f

$$\begin{aligned} A_f &= A_f^T\, e^{i\phi_f^T} \left[1 + r_f\, e^{i(\delta_f + \phi_f)}\right], \\ \bar{A}_f &= \eta_{CP}\, A_f^T\, e^{-i\phi_f^T} \left[1 + r_f e^{i(\delta_f - \phi_f)}\right] \end{aligned}$$

Direct CPV $\iff r_f \neq 0$, $\delta \neq 0$ and $\phi_f \neq 0$

$$a_f^{\rm dir} \equiv \frac{|A_f|^2 - |\bar{A}_f|^2}{|A_f|^2 + |\bar{A}_f|^2} = -2 r_f \sin\delta_f \sin\phi_f$$

- **Effective Hamiltonian**

$$\mathcal{H}^{\mathrm{eff-NP}}_{|\Delta c|=1} = \frac{G_F}{\sqrt{2}} \sum_i C_i Q_i + \mathrm{h.c.}\,,$$

$$\begin{aligned} Q_8 &= \frac{m_c}{4\pi^2}\, \bar{u}_L \sigma_{\mu\nu} T^a g_s G_a^{\mu\nu} c_R\,, \\ \tilde{Q}_8 &= \frac{m_c}{4\pi^2}\, \bar{u}_R \sigma_{\mu\nu} T^a g_s G_a^{\mu\nu} c_L\,. \end{aligned}$$

- **Δa_{CP}: SM + NP**

$$\begin{aligned} \Delta a_{CP} &\approx \frac{-2}{\sin\theta_c}\left[\mathrm{Im}(V_{cb}^* V_{ub})\mathrm{Im}(\Delta R^{\mathrm{SM}}) + \sum_i \mathrm{Im}(C_i^{\mathrm{NP}})\mathrm{Im}(\Delta R^{\mathrm{NP}_i})\right] \\ &= -(0.13\%)\mathrm{Im}(\Delta R^{\mathrm{SM}}) - 9\sum_i \mathrm{Im}(C_i^{\mathrm{NP}})\,\mathrm{Im}(\Delta R^{\mathrm{NP}_i}) \end{aligned}$$

$\Delta R^{\mathrm{SM}} \approx \alpha_s(m_c)/\pi \approx 0.1$ in perturbation theory and $a_K^{\mathrm{dir}} = -a_\pi^{\mathrm{dir}}$ in the $SU(3)$ limit. In naive factorization

$$\left|\mathrm{Im}(\Delta R^{\mathrm{NP}_{8,\tilde{8}}})\right| \approx 0.2$$

- **Direct** "12″ **transition**

$$C_8^{(\tilde{g})} = -\frac{\sqrt{2}\pi\alpha_s\tilde{m}_g}{G_F m_c}\frac{(\delta^u_{12})_{LR}}{\tilde{m}_q^2}\, g_8(x_{gq})\,, \qquad g_8(1) = -\frac{5}{36}$$

- **Effective** "12″ = "13″ × "32″ **transition: quasi-degenerate squarks**

$$C_8^{(\tilde{g})} = -\frac{\sqrt{2}\pi\alpha_s\tilde{m}_g}{G_F m_c}\frac{(\delta^u_{13})_{LL}\,(\delta^u_{33})_{LR}\,(\delta^u_{32})_{RR}}{\tilde{m}_q^2}\, F(x_{gq})\,, \qquad F(1) = -\frac{11}{360}$$

- **Effective** "12″ = "13″ × "32″ **transition: split squark-families**

$$C_8^{(\tilde{g})} = -\frac{\sqrt{2}\pi\alpha_s\tilde{m}_g}{G_F m_c}\frac{(\delta^u_{13})_{LL}\,(\delta^u_{33})_{LR}\,(\delta^u_{32})_{RR}}{\tilde{m}_{q_3}^2}\, g_8(x_{gq})$$

[G.F.Giudice, G.Isidori, & P.P, '12]

- **Δa_{CP} in SUSY**

$$\left|\Delta a_{CP}^{\rm SUSY}\right| \approx 0.6\% \left(\frac{\left|\mathrm{Im}\,(\delta^u_{12})^{eff}_{LR}\right|}{10^{-3}}\right)\left(\frac{\rm TeV}{\tilde m}\right) ,$$

- **Disoriented A terms**

$$\mathrm{Im}\,\left(\delta^u_{12}\right)_{LR} \approx \frac{\mathrm{Im}(A)\,\theta_{12}\; m_c}{\tilde m} \approx \left(\frac{\mathrm{Im}(A)}{3}\right)\left(\frac{\theta_{12}}{0.5}\right)\left(\frac{\rm TeV}{\tilde m}\right) \times 10^{-3} ,$$

- **Split families:** $m_{\tilde q_{1,2}} \gg m_{\tilde q_3}$, $(\delta^u_{33})_{RL} = A\, m_t/m_{\tilde q_3}$

$$\left(\delta^u_{12}\right)^{\rm eff}_{RL} = \left(\delta^u_{13}\right)_{RR}\left(\delta^u_{33}\right)_{RL}\left(\delta^u_{32}\right)_{LL} , \qquad \left(\delta^u_{12}\right)^{\rm eff}_{LR} = \left(\delta^u_{13}\right)_{LL}\left(\delta^u_{33}\right)_{RL}\left(\delta^u_{32}\right)_{RR} .$$

$$\begin{array}{ccc} \left(\delta^u_{32}\right)_{LL} = O(\lambda^2), \quad \left(\delta^u_{13}\right)_{RR} = O(\lambda^2) & \to & \left(\delta^u_{12}\right)^{\rm eff}_{RL} = O(\lambda^4) = O(10^{-3}) , \\ \left(\delta^u_{13}\right)_{LL} = O(\lambda^3), \quad \left(\delta^u_{32}\right)_{RR} = O(\lambda) & \to & \left(\delta^u_{12}\right)^{\rm eff}_{LR} = O(\lambda^4) = O(10^{-3}) . \end{array}$$

[G.F.Giudice, G.Isidori, & P.P, '12]

D^0–$\bar{D}^0$ mixing

- **The D^0–$\bar{D}^0$ transition amplitude can be decomposed into a dispersive (M_{12}) and an absorptive (Γ_{12}) component:**

$$\langle D^0|\mathcal{H}_{\rm eff}|\bar{D}^0\rangle \quad = \quad M_{12}^D - \frac{i}{2}\Gamma_{12}^D \,.$$

- **Physical parameters**

$$x_{12} \equiv 2\frac{|M_{12}^D|}{\Gamma^D}\,, \quad y_{12} \equiv \frac{|\Gamma_{12}^D|}{\Gamma^D}\,, \quad \phi_{12} \equiv \arg\left(\frac{M_{12}^D}{\Gamma_{12}^D}\right)\,,$$

- **The 95% C.L. allowed ranges by HFAG are**

$$x_{12} \in [0.25,\, 0.99]\,\%\,, \qquad y_{12} \in [0.59,\, 0.99]\,\%\,, \qquad \phi_{12} \in [-7.1^\circ,\, 15.8^\circ]\,,$$

- **Effective Hamiltonian**

$$\mathcal{H}_{\rm eff}^{\Delta C=2} = \frac{1}{(1\ {\rm TeV})^2}\sum_i z_i Q_i^{cu} + {\rm H.c.}\,,$$

$$Q_2^{cu} = \bar{u}_R^\alpha c_L^\alpha \bar{u}_R^\beta c_L^\beta\,, \qquad Q_3^{cu} = \bar{u}_R^\alpha c_L^\beta \bar{u}_R^\beta c_L^\alpha\,,$$
$$Q_4^{cu} = \bar{u}_R^\alpha c_L^\alpha \bar{u}_L^\beta c_R^\beta\,, \qquad Q_5^{cu} = \bar{u}_R^\alpha c_L^\beta \bar{u}_L^\beta c_R^\alpha\,,$$

$$|z_2| < 1.6\times 10^{-7}\,, \qquad |z_3| < 5.8\times 10^{-7}\,,$$
$$|z_4| < 5.6\times 10^{-8}\,, \qquad |z_5| < 1.6\times 10^{-7}\,,$$

Δa_{CP} vs. D^0–$\bar{D}^0$ & ϵ'/ϵ in SUSY

- Δa_{CP}

$$\left|\Delta a_{CP}^{\mathrm{SUSY}}\right| \approx 0.6\% \left(\frac{\left|\mathrm{Im}\,(\delta_{12}^u)_{LR}^{eff}\right|}{10^{-3}}\right)\left(\frac{\mathrm{TeV}}{\tilde{m}}\right),$$

- **D^0–$\bar{D}^0$ mixing**

$$z_2^{(\tilde{g})} \approx -5\times 10^{-10}\left(\frac{\mathrm{TeV}}{m_{\tilde{q}}}\right)^2\left[\frac{(\delta_{12}^u)_{RL}}{1\times 10^{-3}}\right]^2,$$

$$z_4^{(\tilde{g})} \approx -2\times 10^{-10}\left(\frac{\mathrm{TeV}}{m_{\tilde{q}}}\right)^2\frac{(\delta_{12}^u)_{LR}\,(\delta_{12}^u)_{RL}}{(1\times 10^{-3})^2},$$

- ϵ'/ϵ

$$\frac{\epsilon'/\epsilon}{(\epsilon'/\epsilon)_{SM}} \sim \frac{(\delta_{12}^u)_{LR}\,(\delta_{22}^u)_{RL}}{\lambda^5}\frac{M_W^2}{\tilde{m}^2} \sim \frac{m_c^2 M_W^2}{\tilde{m}^4}\frac{A^2\theta_{12}^u}{\lambda^5},$$

- Values of $(\delta_{12}^u)_{LR,RL} \sim 10^{-3}$ leading to $\Delta a_{CP} \approx 0.6\%$ are well below the current bounds from $D^0 - \bar{D}^0$ mixing
- NP contribution to ϵ'/ϵ are generated through loops of charginos and up-squarks, but they are suppressed by $(\delta_{12}^u)_{LR}\,(\delta_{22}^u)_{RL}/\tilde{m}^2 \sim m_c^2/\tilde{m}^4$ and therefore they remains insignificant, even for $(\delta_{12}^u)_{LR} \sim 10^{-3}$.

Δa_{CP} in SUSY

- **Disoriented A terms**

$$(\delta^q_{ij})_{LR} \sim \frac{A\theta^q_{ij} m_{q_j}}{\tilde{m}} \qquad q = u, d \ ,$$

	θ^q_{11}	θ^q_{12}	θ^q_{13}	θ^q_{23}
q=d	< 0.2	< 0.5	< 1	–
q=u	< 0.2	–	< 0.3	< 1

[G.F.Giudice, G.Isidori, & P.P, '12]

- Down-quark FCNC (in particular ϵ'/ϵ and $b \to s\gamma$) are under control thanks to the smallness of m_{down}
- EDMs are suppressed by $m_{u,d}$ (yet they are quite enhanced)
- Up-quark FCNC (induced by gluino & up-squarks) and Down-quark FCNC like $K \to \pi\nu\nu$ and $B_{s,d} \to \mu\mu$ (induced by charginos & up-squarks) receive the largest effects from disoriented A terms.

Δa_{CP} in SUSY alignment models

- In SUSY alignment models it turns out that

$$\left(\delta^u_{21}\right)^{\text{eff}}_{RL} = \left(\delta^u_{22}\right)_{RL}\left(\delta^u_{21}\right)_{LL} \sim \frac{Am_c}{\tilde{m}}\lambda.$$

- $(\delta^u_{21})_{LL} \sim \lambda$ arises from the $SU(2)$ relation $\tilde{M}^{(u)2}_{LL} = V\tilde{M}^{(d)2}_{LL}V^\dagger$ and the assumption of non-degeneracy for different squark families

$$(\tilde{M}^{(u)2}_{LL})_{21} \approx (\tilde{M}^{(d)2}_{LL})_{21} + \lambda\left[(\tilde{M}^{(d)2}_{LL})_{22} - (\tilde{M}^{(d)2}_{LL})_{11}\right] .$$

$$\left(\delta^u_{21}\right)_{LL} \approx \lambda\,\frac{\Delta\tilde{m}^2_{21}}{\tilde{m}^2}\ ,$$

- The bounds from D–$\bar{D}$ mixing imply $|\,(\delta^u_{21})_{LL}\,| < 3\times 10^{-2}$ for TeV squarks, and $(\delta^u_{22})_{RL} \approx Am_c/\tilde{m} < 10^{-3}$ from vacuum stability.
- Therefore, in SUSY alignment models $\Delta a^{\rm SUSY}_{CP}$ is predicted to be well below the central LHCb value.

Δa_{CP} in SUSY with split squark families

- **Δa_{CP} in the split family scenario**

$$\Delta a_{CP} \approx 2 \times \mathrm{Im}\, C_8^{(\tilde{g})} = -\frac{2\sqrt{2}\pi\alpha_s \tilde{m}_g}{G_F m_c} \frac{\mathrm{Im}\left[(\delta^u_{13})_{LL}\,(\delta^u_{33})_{LR}\,(\delta^u_{32})_{RR}\right]}{\tilde{m}^2_{q_3}}\; g_8(x_{gq})$$

- **EDMs in the split family scenario**

$$\left\{\frac{d_u}{e},\; d^c_u\right\} = -\frac{\alpha_s m_{\tilde{g}}}{2\pi \tilde{m}^2_{q_3}}\; f_3^{d_u, d^c_u}(x_{gq})\, \mathrm{Im}\left[(\delta^u_{13})_{LL}(\delta^u_{33})_{LR}(\delta^u_{31})_{RR}\right]\;,$$

- **Δa_{CP} vs. the neutron EDM in the split family scenario**

$$\left|\Delta a^{\mathrm{SUSY}}_{CP}\right| \approx 2 \times 10^{-3} \times \left|\frac{d_n}{3 \times 10^{-26}}\right| \left|\frac{\mathrm{Im}\,(\delta^u_{32})_{RR}}{0.2}\right| \left|\frac{10^{-3}}{\mathrm{Im}\,(\delta^u_{31})_{RR}}\right|\;.$$

where $(\delta^u_{33})_{RL} \approx A\, m_t/\tilde{m}$. A strong hierarchical structure in the off-diagonal terms of the RR up-squark mass matrix is required. This happens for instance models of alignment

$$(\delta^u_{ij})_{RR} \sim \frac{m_{u_i}/m_{u_j}}{|V_{ij}|} \;\Rightarrow\; \frac{(\delta^u_{31})_{RR}}{(\delta^u_{32})_{RR}} \sim \frac{m_u}{\lambda m_c} \sim 10^{-2}$$

[G.F.Giudice, G.Isidori, & P.P, '12]

Formalism for $B_{d,s}$ mixing amplitudes

- **Theory:**

$$M_{12}^q = \left(M_{12}^q\right)_{\rm SM} C_{B_q} e^{2i\varphi_{B_q}} \,, \qquad \Delta M_q = 2\left|M_{12}^q\right| = (\Delta M_q)_{\rm SM} C_{B_q} \qquad (q=d,s)\,.$$

$$S_{\psi K_S} = \sin(2\beta + 2\varphi_{B_d})\,, \qquad S_{\psi\phi} = \sin(2|\beta_s| - 2\varphi_{B_s})\,,$$

$$\sin(2\beta)_{\rm tree} = 0.775 \pm 0.035\,, \qquad \sin(2\beta_s)_{\rm tree} = 0.038 \pm 0.003 \qquad (\text{CKM fit}).$$

- **Experiments:**

$$S_{\psi K_S}^{\rm exp} = 0.676 \pm 0.020\,, \qquad S_{\psi\phi(f_0)}^{\rm exp} = -0.03 \pm 0.18\,.$$

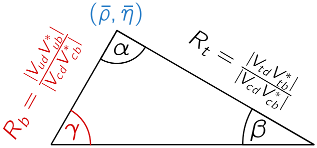
- **Δa_{CP} vs. $S_{\psi K_S}$ in SUSY with split squark families**

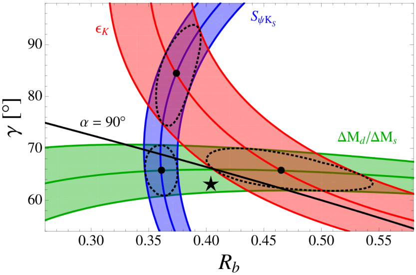
$$M_{12}^q \approx \left(M_{12}^q\right)^{\rm SM}\left[1 + \frac{\left(\delta_{3q}^d\right)_{LL}^2}{V_{tq}^2} F_0\right]\,, \qquad F_0 \approx \frac{1}{3}\left(\frac{g_s}{g}\right)^4 \frac{m_W^2}{\tilde{m}_{q_3}^2}$$

$$\Delta a_{CP} \sim {\rm Im}\left[\left(\delta_{13}^u\right)_{LL}\left(\delta_{33}^u\right)_{LR}\left(\delta_{32}^u\right)_{RR}\right]\,, \qquad (\Delta S_{\psi K_S})_{\rm NP} \sim {\rm Im}\left[\frac{\left(\delta_{31}^d\right)_{LL}^2}{V_{td}^2}\right]$$

UT tensions and NP

- "Tensions" in the the UT analysis
- Look at ϵ_K, $S_{\psi K_S}$, and $\Delta M_d/\Delta M_s$ in the R_b-γ plane from tree-level processes





[Altmannshofer, Buras, Gori, P.P, Straub, '09; Buras, Nagai, P.P, '10]

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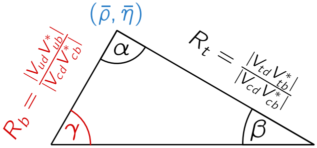

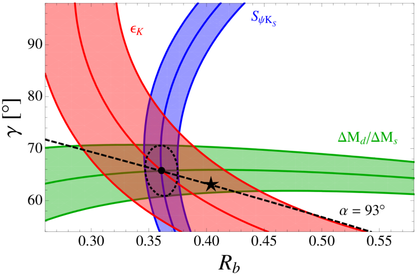

Possible solutions:

1. $+24\%$ NP effect in ϵ_K

[Altmannshofer, Buras, Gori, P.P, Straub, '09; Buras, Nagai, P.P, '10]

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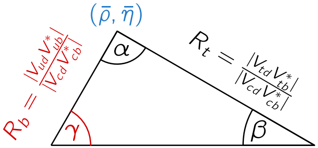

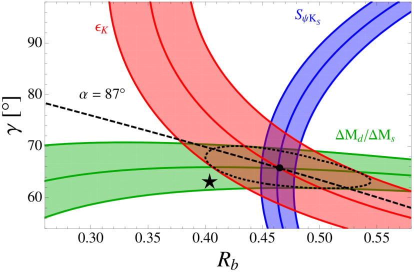

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2. $-6.5°$ NP phase in B_d mixing

[Altmannshofer, Buras, Gori, P.P, Straub, '09; Buras, Nagai, P.P, '10]

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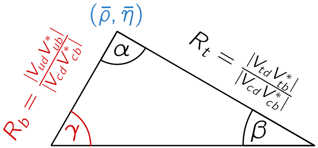
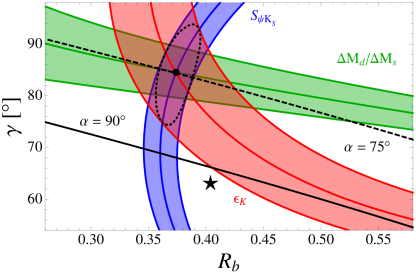
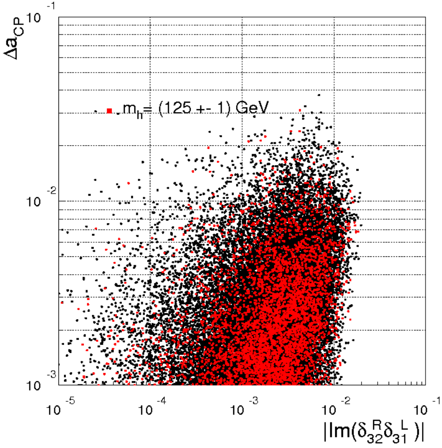


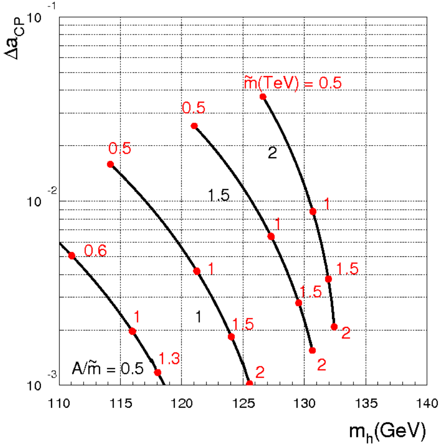


Possible solutions:

1. $+24\%$ NP effect in ϵ_K
2. $-6.5°$ NP phase in B_d mixing
3. -22% NP effect in $\Delta M_d/\Delta M_s$

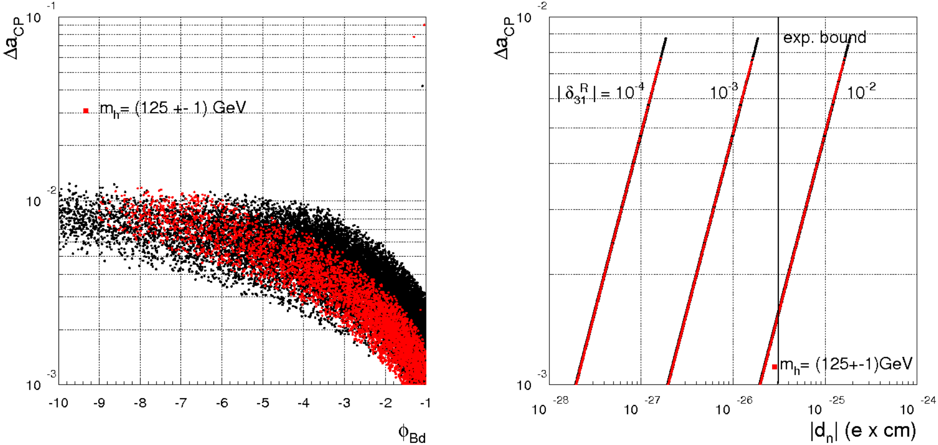
[Altmannshofer, Buras, Gori, P.P, Straub, '09; Buras, Nagai, P.P, '10]





Left: 0.5 TeV $\leq \tilde{m}, \tilde{m}_g \leq 2$ TeV, $\tan\beta = 10$, $|A| \leq 3$.
Right: $|\mathrm{Im}[(\delta^u_{32})_{RR}(\delta^u_{31})_{LL}]| = 10^{-2}$, $\tilde{m} \leq 2$ TeV, and $A = 0.5, 1, 1.5, 2$.

Δa_{CP} and SUSY [G.F.Giudice, G.Isidori, & P.P, '12]



Left: $(\delta^u_{32})_{RR} = 0.2$ and $\phi_{\delta^L_{31}} \in \pm(30^\circ, 60^\circ)$, $|(\delta^d_{31})_{LL}| < 0.1$.

Right: $(\delta^u_{13})_{LL} = 10^{-2}$, $(\delta^u_{32})_{RR} = 0.2i$.

- The effective $\Delta C = 1$ transition through stops opens up the possibility of observing flavor violations in the up-quark sector at the LHC.
  - **Production processes:** $pp \to \tilde{t}^* \tilde{u}_i$, where $\tilde{u}_i = \tilde{u}, \tilde{c}$. The rate for single $\tilde{u}_i$ production in association with a single stop is proportional to $(\delta^u_{i3})^2_{RR}$, since the mixings in the right-handed sector are larger then in the left sector.
  - **Flavor-violating stop decays**

$$\frac{\Gamma(\tilde{t} \to c\chi^0)}{\Gamma(\tilde{t} \to t\chi^0)} = \left|(\delta^u_{i3})_{RR}\right|^2 \left(1 - \frac{m_t^2}{\tilde{m}_t^2}\right)^{-2},$$

    where $u_i = u, c$ and χ^0 is the lightest neutralino.
  - **Flavor-violating gluino decays**

$$\frac{\Gamma(\tilde{g} \to \tilde{t} u_i)}{\Gamma(\tilde{g} \to \tilde{t} t)} = \left|(\delta^u_{i3})_{RR}\right|^2 \left[1 + O\left(\frac{m_t}{\tilde{m}_g}\right)\right].$$

    In models with split families, the gluino can decay only into $\tilde{g} \to \bar{t}\tilde{t},\ \bar{b}\tilde{b}$. Once we include flavor violation, the decay $\tilde{g} \to \bar{u}_i \tilde{t}$ is also allowed
  - **Flavor-violating top decays**

$$\mathrm{BR}(t \to qX) \sim \left(\frac{\alpha}{4\pi}\right)^2 \left(\frac{m_W}{m_{\mathrm{SUSY}}}\right)^4 |\delta^u_{3q}|^2$$

    where $m_{\mathrm{SUSY}} = \max(m_{\tilde{g}}, m_{\tilde{t}})$ for $X = \gamma, g, Z$ and $m_{\mathrm{SUSY}} = m_A$ for $X = h$. Even for $\delta^u_{3q} \sim 1$ and $m_{\mathrm{SUSY}} \gtrsim 3 m_W$, $\mathrm{BR}(t \to qX) \lesssim 10^{-6}$.

- **Effective Lagrangian for FCNC couplings of the Z-boson to fermions**

$$\mathcal{L}_{\rm eff}^{Z-{\rm FCNC}} = -\frac{g}{2\cos\theta_W}\bar{F}_i\gamma^\mu \left[(g_L^Z)_{ij}\, P_L + (g_R^Z)_{ij}\, P_R\right] q_j\, Z_\mu + \text{ h.c.}$$

F can be either a SM quark ($F = q$) or some heavier non-standard fermion. If F is a SM fermion

$$(g_L^Z)_{ij} = \frac{v^2}{M_{\rm NP}^2}(\lambda_L^Z)_{ij} \qquad (g_R^Z)_{ij} = \frac{v^2}{M_{\rm NP}^2}(\lambda_R^Z)_{ij}$$

- **Direct CPV in charm**

$$\left|\Delta a_{CP}^{Z-{\rm FCNC}}\right| \approx 0.6\% \left|\frac{{\rm Im}\left[(g_L^Z)^*_{ut}(g_R^Z)_{ct}\right]}{2\times 10^{-4}}\right| \approx 0.6\% \left|\frac{{\rm Im}\left[(\lambda_L^Z)^*_{ut}(\lambda_R^Z)_{ct}\right]}{5\times 10^{-2}}\right| \left(\frac{1\ {\rm TeV}}{M_{\rm NP}}\right)^4$$

- **Neutron EDM**

$$|d_n| \approx 3\times 10^{-26}\left|\frac{{\rm Im}\left[(g_L^Z)^*_{ut}(g_R^Z)_{ut}\right]}{2\times 10^{-7}}\right|\ e\,{\rm cm}$$

- **Top FCNC**

$${\rm Br}(t\to cZ) \approx 0.7\times 10^{-2}\left|\frac{(g_R^Z)_{tc}}{10^{-1}}\right|^2$$

Top FCNC

- **Effective Lagrangian**

$$
\begin{aligned}
-\mathcal{L}^{\mathrm{eff}} &= \frac{g}{2c_W}\bar{q}\gamma_\mu\left(g^{qt}_{ZL}P_L + g^{qt}_{ZR}P_R\right)tZ^\mu + \frac{e}{2m_t}\bar{q}\left(g^{qt}_{\gamma L}P_L + g^{qt}_{\gamma R}P_R\right)\sigma_{\mu\nu}tF^{\mu\nu} \\
&+ \frac{g_s}{2m_t}\bar{q}\left(g^{qt}_{gL}P_L + g^{qt}_{gR}P_R\right)\sigma_{\mu\nu}T^a tG^{a\mu\nu} + \bar{q}\left(g^{qt}_{hL}P_L + g^{qt}_{hR}P_R\right)tH + \mathrm{h.c.}
\end{aligned}
$$

- **Top FCNC decay widths**

$$
\begin{aligned}
\Gamma(t\to qZ) &= \frac{\alpha_2}{32c_W^2}|g^{qt}_Z|^2\frac{m_t^3}{m_Z^2}\left(1-\frac{m_Z^2}{m_t^2}\right)^2\left(1+2\frac{m_Z^2}{m_t^2}\right), \\
\Gamma(t\to q\gamma) &= \frac{\alpha}{4}|g^{qt}_\gamma|^2 m_t\,, \\
\Gamma(t\to qg) &= \frac{\alpha_s}{3}|g^{qt}_\gamma|^2 m_t\,, \\
\Gamma(t\to qH) &= \frac{m_t}{32\pi}|g^{qt}_h|^2\left(1-\frac{M_H^2}{m_t^2}\right)^2,
\end{aligned}
$$

where $|g^{qt}_X|^2 = (|g^{qt}_{XL}|^2 + |g^{qt}_{XR}|^2)$ with $X = Z, \gamma, g, h$.

New-physics scenarios with scalar-mediated FCNC

- **Effective Lagrangian for FCNC scalar couplings to fermions**

$$\mathcal{L}_{\rm eff}^{h-\rm FCNC} = -\bar{q}_i \left[(g_L^h)_{ij}\, P_L + (g_R^h)_{ij}\, P_R \right] q_j\ h + \text{ h.c.}\,,$$

$$(g_L^h)_{ij} = \frac{v^2}{M_{\rm NP}^2} (\lambda_L^h)_{ij}\,, \qquad (g_R^h)_{ij} = \frac{v^2}{M_{\rm NP}^2} (\lambda_R^h)_{ij}\,,$$

- **Direct CPV in charm**

$$\left| \Delta a_{CP}^{h-\rm FCNC} \right| \approx 0.6\% \left| \frac{\mathrm{Im}\left[(g_L^h)^*_{ut} (g_R^h)_{tc} \right]}{2 \times 10^{-4}} \right| \approx 0.6\% \left| \frac{\mathrm{Im}\left[(\lambda_L^h)^*_{ut} (\lambda_R^h)_{ct} \right]}{5 \times 10^{-2}} \right| \left(\frac{1 \text{ TeV}}{M_{\rm NP}} \right)^4 .$$

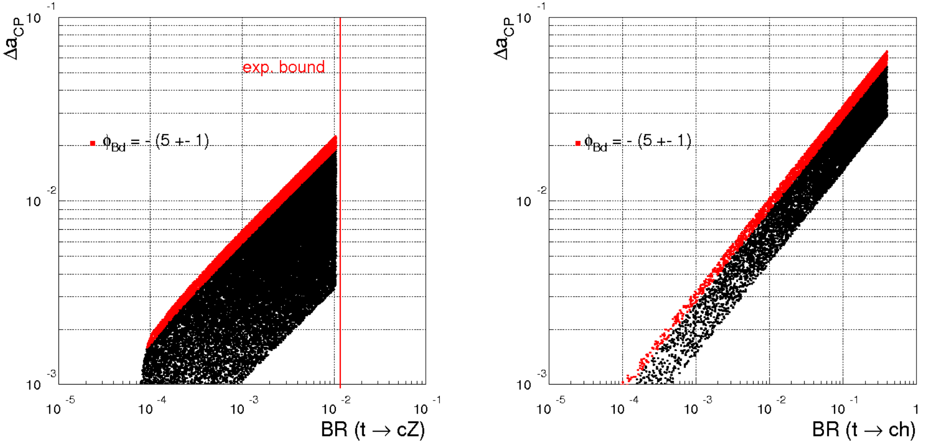
- **Neutron EDM**

$$|d_n| \approx 3 \times 10^{-26} \left| \frac{\mathrm{Im}\left[(g_L^h)^*_{ut} (g_R^h)_{tu} \right]}{2 \times 10^{-7}} \right| \ e\,\mathrm{cm}\,,$$

- **Top FCNC**

$$\mathrm{Br}(t \to qh) \approx 0.4 \times 10^{-2} \left| \frac{(g_R^h)^{tq}}{10^{-1}} \right|^2 ,$$

Δa_{CP} in scenarios with Z- and scalar-mediated FCNC [G.F.Giudice, G.Isidori, & P.P,



Left: $\mathrm{BR}(t \to cZ)$ vs. $\Delta a_{CP}^{Z-\mathrm{FCNC}}$. Right: $\mathrm{BR}(t \to ch)$ vs. $\Delta a_{CP}^{h-\mathrm{FCNC}}$. The plots have been obtained by means of the scan: $|(g_L^X)_{ut}| > 10^{-3}$, $|(g_R^X)_{ct}| > 10^{-2}$, where $X = Z, h$, with $\arg[(g_L^X)_{ut}] = \pm\pi/4$ and $\arg[(g_R^X)_{ct}] = 0$. The points in the red regions solve the tension in the CKM fits through a non-standard phase in B_d–$\bar{B}_d$ mixing, assuming for the corresponding down-type coupling $(g_L^X)_{db} = 5 \times 10^{-2}(g_L^X)_{ut}$.

CPV in $\mathbf{D^0} - \overline{\mathbf{D}}^{\mathbf{0}} \sim \mathrm{Im}((V_{cb}V_{ub})/(V_{cs}V_{us})) \sim \mathbf{10^{-3}}$ in the **SM**

- $\langle D^0|\mathcal{H}_{\rm eff}|\bar{D}^0\rangle = M_{12} - \frac{i}{2}\Gamma_{12}, \qquad |D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$
- $\frac{q}{p} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}, \qquad \phi = \mathrm{Arg}(q/p)$
- $x = \frac{\Delta M_D}{\Gamma} = 2\tau \mathrm{Re}\left[\frac{q}{p}\left(M_{12} - \frac{i}{2}\Gamma_{12}\right)\right]$
- $y = \frac{\Delta\Gamma}{2\Gamma} = -2\tau \mathrm{Im}\left[\frac{q}{p}\left(M_{12} - \frac{i}{2}\Gamma_{12}\right)\right]$

$$\mathbf{S_f} = 2\Delta Y_f = \frac{1}{\Gamma_D}\left(\hat{\Gamma}_{\bar{D}^0\to f} - \hat{\Gamma}_{D^0\to f}\right)$$

$$\eta_f^{\rm CP} S_f = x\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right)\sin\phi - y\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right)\cos\phi$$

$$\mathbf{a}_{\rm SL} = \frac{\Gamma(D^0 \to K^+\ell^-\nu) - \Gamma(\bar{D}^0 \to K^-\ell^+\nu)}{\Gamma(D^0 \to K^+\ell^-\nu) + \Gamma(\bar{D}^0 \to K^-\ell^+\nu)} = \frac{|q|^4 - |p|^4}{|q|^4 + |p|^4}$$

[Nir et al.,Kagan et al., Petrov et al., Bigi et al., Buras et al., ...]

CPV in D-physics vs. neutron EDM in SUSY [Altmannshofer, Buras, & P.P, '10]

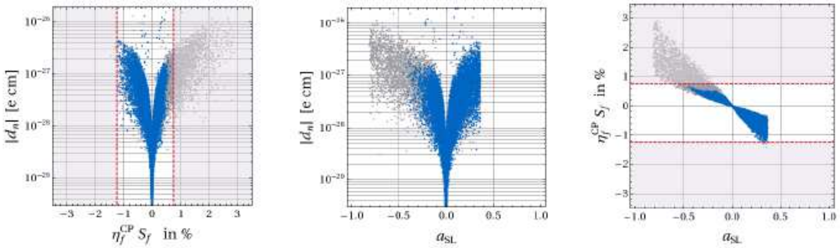


FIG. 3: Correlations between d_n and S_f (left), d_n and $a_{\rm SL}$ (middle) and $a_{\rm SL}$ and S_f (right) in SUSY alignment models. Gray points satisfy the constraints (8)-(10) while blue points further satisfy the constraint (11) from ϕ. Dashed lines stand for the allowed range (18) for S_f.

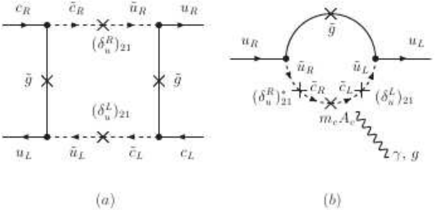


FIG. 2: Examples of relevant Feynman diagrams contributing (a) to $D^0 - \bar{D}^0$ mixing and (b) to the up quark (C)EDM in SUSY alignment models.

Conclusions and future prospects

- **The important questions in view of future experiments are**:
  - What are the expected deviations from the SM predictions induced by TeV NP?
  - Which observables are not limited by theoretical uncertainties?
  - In which case we can expect a substantial improvement on the experimental side?
  - What will the measurements teach us if deviations from the SM are [not] seen?

- **Our (personal) answers are**:
  - The expected deviations from the SM predictions induced by NP at the TeV scale with generic flavor structure are already ruled out by many orders of magnitudes.
  - On general grounds, we can expect any size of deviation below the current bounds.
  - The theoretical limitations are highly process dependent. Several channels involving leptons in the final state, and selected time-dependent asymmetries, have a theoretical errors well below the current experimental sensitivity.
  - On the experimental side there are excellent prospects of improvements. One order of magnitude improvements in several clean $B_{s,d}$, D, K, and π (LFU tests in $\pi_{\ell 2}$) observables are possible within a few years. Improvements of several orders of magnitudes are expected in LFV processes ($\mu \to e\gamma$, $\mu Ti \to e Ti$) and EDM experiments (d_n, d_{Tl}).

Conclusions and future prospects

- **There is no doubt that new low-energy flavor data will be complementary with the high-p_T part of the LHC program.**
- **The synergy of both data sets can teach us a lot about the new physics at the TeV scale.**
- **CPV in charm will play an important role**